The Nuclear System-of-Systems Capabilities Analytic Process

A Dissertation Presented for the

Doctor of Philosophy

Degree

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To my loving wife, Jessica and our sons, Thomas and Samuel.

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Greater love hath no man than this,
that a man lay down his life for his friends.

John 15:13, KJV

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Abstract

This work includes the first known capabilities-based vulnerability analysis process able to evaluate a system of systems exposed to nuclear weapon environments: the Nuclear System-of-Systems Capabilities Analytic Process (NuSCAP™). This approach, executed by an automated Python® application, calculates the magnitudes of eight nuclear weapon environment quantities by calling on the US Strategic Command Probability of Damage Calculator (PDCALC) code, the Los Alamos National Laboratory Simple Nuclear Effects Calculator (SNEC) program, and the Monte Carlo N-Particle® (MCNP®) code. Calculated nuclear weapon environment values are compared with user-provided dysfunction thresholds for all components, subsystems, and systems in the model to determine the functionality of each model element. Residual system- and system-of-systems-level functionality and capabilities are determined by traversing paths through a graph of the system-of-systems architecture. Capabilities are reported according to discrete degraded-states metrics determined by traversing the graph using Dijkstra's algorithm. Results are delivered as JSON output files and visual depictions of the graphs.

Three case studies demonstrate NuSCAP's ability to provide system-of-systems vulnerability analyses in three distinct nuclear weapon detonation scenarios. These studies analyze a representative, conventional, US Army system of systems exposed to a 10 kiloton nuclear weapon detonation. Ground ranges between the detonation and the target systems considered in the case studies span from a few meters to almost four kilometers. Results are based on notional, but reasonable, dysfunction thresholds because actual failure levels for most components are currently unavailable. The three case studies demonstrate NuSCAP's ability to adjudicate nuclear weapon effects on military targets and aggregate damage in order to resolve the maximum residual capabilities of a military system of systems. Capabilities assessed include electric power generation, communication, target observation and identification, and weapon system engagement that all support fundamental needs of military units to shoot, move, and communicate.

Requisite data, sources of those data, challenges to realistic modeling and simulations, and future areas of research are discussed. NuSCAP application Python packages, data files, and output files are also provided.

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Nomenclature

2-VNTK	*See* VNTK An alphaneumeric expression based on the VNTK concept but expanded to account for blast loading on both lateral (wall) and horizontal (roof) surfaces of large, drag-sensitive targets in urban and industrial areas [15, p. 44].
3-D	three-dimensional
AAR	after-action review
ADP	Army Doctrine Publication
AFSWP	Armed Forces Special Weapons Project, a predecessor of DTRA. *See* DTRA
AGZ	actual ground zero
ARL	United States Army Research Laboratory; previously known the U.S. Army Ballistic Research Laboratory
AS	associate of science
ATP	Army Techniques Publication
ATR	Air Transport of Radiation (computer code)
AURA	Army Unit Resiliency Analysis
BS	bachelor of science
BTR	Bronetransportyor (from the Russian), armored transporter vehicle
C-AAC	Actinide Analytical Chemistry group

CAD	computer-aided design
CBRN	chemical, biological, radiological, and nuclear
CCD	Combat Capability Degradation (computational model)
CEP	circular error probable
CFD	computational fluid dynamics
CLC3	Combined Logistics Captains Career Course
CNI	conventional-nuclear integration
CSG	constructive solid geometry
CWMD	countering weapons of mass destruction
DAG	directed, acyclic graph
DASA	Defense Atomic Support Agency, a predecessor of DTRA. *See* DTRA
dict	dictionary (data type)
DNA	Defense Nuclear Agency, a predecessor of DTRA. *See* DTRA
DNAWE	Defense Nuclear Agency Weapon Effects (computer code)
DoD	United States Department of Defense
DOTMLPF-P	doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy DOTMLPF-P domains provide a framework by which the Department of Defense may design changes and acquisition programs to fill capability gaps.
DSWA	Defense Special Weapons Agency, a predecessor of DTRA. *See* DTRA
DTG	date time group, given in DD HHMMZ MON YYYY format [16, p. 2-2]
DTIC	Defense Technical Information Center

DTRA	Defense Threat Reduction Agency The Defense Threat Reduction Agency (1998–present) has been known by many different monikers throughout its history, including: the Armed Forces Special Weapons Project (AFSWP, 1946–1959), the Defense Atomic Support Agency (DASA, 1959–1971), the Defense Nuclear Agency (DNA, 1971–1996), and the Defense Special Weapons Agency (DSWA, 1996–1998).
EFP	explosively formed projectile
EMP	electromagnetic pulse
EMREP	ElectroMagnetic Reliability and Effects Predictions program
ERA	explosive reactive armor
ERC	equipment readiness code
FBR	fast burst reactor
FEA	finite element analysis
FFHOB	fallout-free height of burst
float	floating point number (data type)
FM	Field Manual
FS	functional skeleton
G-VN	ground-shock vulnerability number A 10-character alphaneumeric expression based on the VNTK concept that represents a deeply buried (>20 meters) target's susceptibility to damage by nuclear effects [17, slides 31–40]. *See* VNTK
GA	General of the Army (5-star, OF/O-10)
GEN	General (4-star, OF/O-10)
GPF	gamma-ray protection factor
GRP	glass-reinforced plastic

GWOT	Global War on Terrorism
HANE	high-altitude nuclear explosion
HEMP	high-altitude electromagnetic pulse
HEMPTAPS	High-Altitude Electromagnetic Pulse Target Analysis and Planning System
HEU	highly enriched uranium
HMMWV	high-mobility, multipurpose, wheeled vehicle
HOB	height of burst
HSV	hue saturation value color model
HSVA	hue saturation value, alpha color model
IED	improvised explosive device
IND	improvised nuclear device
int	integer (data type)
JCIDS	Joint Capabilities Integration and Development System
KERMA	kinetic energy release in material [18, p. 80]
kt	kiloton Equivalent to 10^{12} calories; this is the standard unit of measure for the explosive energy yield of a nuclear weapon. One kiloton is roughly equal to the energy liberated during the explosion of 1,000 short tons of TNT at 1,102 calories per gram or to 1,000 long tons of TNT at 984 calories per gram [19, p. 13].
LANL	Los Alamos National Laboratory
LOF	loss of function
LRU	line-replaceable uniit
M&S	modeling and simulations
MASH	Monte Carlo Adjoint Shielding (computer code)

MBT&E	mission-based test and evaluation
MCNP®	Monte Carlo N-Particle® (computer code)
MGRS	military grid reference system
MMF	mission and means framework
mph	miles per hour
MS	master of science
MSL	mean sea level
Mt	megaton See kiloton (kt). One megaton is equivalent to one thousand kilotons.
MTOE	modified table of organization and equipment
MUVES	Modular UNIX®-based Vulnerability Estimation Suite (computer code)
MWO	modification work order
NBCRV	Nuclear Biological Chemical Reconnaissance Vehicle–Stryker
NPF	neutron protection factor
NPR	Nuclear Posture Review
NRL	Naval Research Laboratory
NSIS	Office of National Security and International Studies
NSRC	Nuclear Science and Engineering Research Center
NUDACC	Nuclear Damage Assessment Computer Code
NuSCAP™	Nuclear System-of-Systems Capabilities Analytic Process™
PANE	Department of Physics and Nuclear Engineering, US Military Academy
PD	probability of damage
PDCALC	Probability of Damage Calculator (computer code)

PDF	probability density function
PEO	program executive office
PhD	doctor of philosophy
psi	pounds per square inch
RBE	relative biological effectiveness
RCC	Residual Combat Capability
RDD	radiological dispersal device
RGB	red, gree, blue color model
RGBA	red, gree, blue, alpha color model
RINKE	resiliency in nuclear and kinetic environments
RKC	required kill criterion
ROTC	Reserve Officer Training Corps
RPF	radiation protection factor
RPP	rectangular parallelepiped A 6-faced polyhedron all of whose faces are rectangles lying in pairs of parallel planes; *adapted from* [20, p. 1324]
S4	System of Systems Survivability Simulation
SAA	Strategic Analyses and Assessments office
SCAP	System Capabilities Analytic Process
ScDF	analytical scenario data file
SDEF	source definition card
SDF	system data file
SLV	survivability, lethality, and vulnerability
SLVA	survivability, lethality, and vulnerability analysis

SNEC	Simple Nuclear Effects Calculator (computer application)
SOS	system of systems
SOSDF	system-of-systems data file
SOSVA	system-of-systems vulnerability analysis
SREMPTAPS	Source Region Electromagnetic Pulse Target Analysis and Planning System
STP	Soldier Training Publication
str	string (data type)
STRIPS	Stanford Research Institute Problem Solver
SWORD	SoftWare for Optimization of Radiation Detectors
T&E	test and evaluation
TC	Training Circular
TM	technical manual
TNF/S	Theater Nuclear Force Survivability
TNT	trinitrotoluene, also known as 2-methyl-1,3,5-trinitro-benzene; CAS RN®: 118-96-7
UAV	unmanned aerial vehicle
UM	unstructured mesh
USANCA	US Army Nuclear and Countering Weapons of Mass Destruction Agency
USSTRATCOM	United States Strategic Command
V&V	verification and validation
VNTK	vulnerability number with T and K factors A 4-character alphaneumeric expression that represents a target's sensitivity to damage by nuclear weapon effects [21, p. 19–26]
WSMR	White Sands Missile Range
XCP-7	Radiation Transport Applications group

Chapter 1

Introduction

The way to win an atomic war is to make certain it never starts.

General of the Army (GA) Omar N. Bradley

This dissertation discusses the impetus for, development of, and initial demonstration of NuSCAP™: the Nuclear System-of-Systems Capabilities Analytic Process™. NuSCAP is an approach executed via a Python® application that enables capabilities-based vulnerability analyses of military systems of systems (SOS) exposed to prompt nuclear weapon effects. The NuSCAP application calls on industry-standard, fast-running nuclear weapon effects tools and the Monte Carlo N-Particle®[1] (MCNP®) code [22] to evaluate the impact of nuclear weapon environments on the military capabilities of a complex and networked SOS.

1.1 Impetus for Developing NuSCAP

The development of the NuSCAP method and application is predicated on the desire of entities within the US Department of Defense (DoD) to understand the potential impacts of nuclear weapon detonations on the modern battlefield—specifically how those detonations impact interconnected SOS deployed today and on battlefields of the future. By developing NuSCAP as a tool with which the DoD and its supporting agencies are able to quantify the functionality of a current or future SOS and, if functional, ascertain what residual capabilities remain at the disposal of the commander on the ground, a significant capability is provided.

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Providing this novel analytical capability advances the fields of nuclear engineering, systems engineering, and vulnerability analyses while directly supporting nascent national security objectives.

1.1.1 Providing a Desired Capability

Of its 1,026 nuclear weapon tests conducted between 1945 and 1992, the United States performed exactly 100 [23, table 5] for the express purpose of evaluating nuclear weapon effects on various targets. During the United States' above-ground weapons effects tests, military targets exposed to nuclear weapons environments generally fell into two broad categories. The first category comprises fully equipped or specially instrumented ships, aircraft, vehicles, and ancillary equipment that were exposed to prompt nuclear weapon effects and assessed for damage following the nuclear detonation(s) [24–30]. These equipment were static, unmanned, and non-operational. Some were put into operation afterward to determine their residual level of functionality [26]. Others were simply categorized based on observed damage and discarded [25–30]. The second category included functional, fully equipped vehicles, equipment, and personnel present during a detonation but stationed in protected positions and/or at such great distances from the detonation that they experienced no appreciable prompt nuclear weapon effects. Some time after the detonation, these personnel and equipment conducted rudimentary military actions in the post-detonation environment [25, 28–30]. Some exceptions to these categories are reported as individual aircraft and sea-going vessels used for troop transport and instrument-carrying platforms that were in operation during several tests [25, 26, 28–35].

Aside from the few aforementioned air and sea transport platforms, no available records reflect any of the United States' 100 nuclear weapon effects tests assessing the impact of prompt nuclear weapon effects on military SOSs actively performing warfighting missions. The reports that exist document little about the functional state of the transport platforms themselves. Likewise, the second- and third-order effects of damage to one or more elements of an integrated SOS performing its designated warfighting mission are not reported. (For the purposes of this work, second- and third-order effects may be thought of as the limitation(s) damage or loss of a component in one or more system(s) (e.g., the transmission in a main battle tank) impose on the greater system architecture. Following this example, the second-order effects include the limitation on that particular tank's ability to maneuver. The third-order effects manifest themselves as the ability of that tank to perform its mission (e.g., conduct an attack).) It is also worth noting that since the US ceased full-scale nuclear weapon testing in 1992, no military equipment developed since has been exposed to actual nuclear weapon environments.

Although the Defense Threat Reduction Agency (DTRA) reports the existence of over 500 nuclear weapon

effects modeling and simulation computer codes [36], neither a method of analysis or a tool that permits a capabilities-based analysis of a networked military SOS exposed to a nuclear detonation is found in the literature. A discussion of historic and contemporary system-of-systems vulnerability analysis (SOSVA) methods, their capabilities, and their limitations follows in chapter 2.

1.1.2 Support to National Security Objectives

In January 2020, the US Army Chief of Staff, General (GEN) James McConville emphasized the presence of an inflection point between the irregular warfare, counterterrorism, and counterinsurgency operations in Iraq, Afghanistan, and Syria and tomorrow's military challenges [37]. GEN McConville went on to categorically declare that nuclear weapons constitute the most concerning Chinese and Russian capabilities in the current era of Great Power Competition [37]—a point underpinned by the current National Defense Strategy [38]. His comments are but one example of numerous United States military and civilian leaders placing renewed emphasis on integrated deterrence, nuclear survivability, and conventional-nuclear integration (CNI). Four strategic documents [38, 39] published in 2022 codify this renewal, provide direction to the US Joint Force, and send a clear message of US intent to our allies, partners, and competitors alike.

The 2022 Nuclear Posture Review (NPR) [38] asserts:

> When engaged in conventional operations against a nuclear-armed adversary the Joint Force must be able to survive, maintain cohesion, and continue to operate in the face of limited nuclear attacks...It is also critically important that the Joint Force can fight and win in a chemical, biological, radiological, and nuclear (CBRN)-contaminated environment. Further development of plans and force requirements to enable military operations in a nuclear environment will be a focus of NPR implementation, including requirements to ensure the resilience of conventional systems to limited nuclear use effects and enhanced mission assurance of space assets critical to conventional force operations.

Likewise, the Army's CNI strategy states that the US Army must be able to "exploit its resiliency advantage" [39] thus enabling it to "dominate operations in and through a nuclear environment" [39]. Expounding on these imperatives, the CNI strategy document stipulates, "Required resiliency includes both surviving the effects of nuclear weapon employment and maintaining an operational mindset and sustained combat effectiveness to continue" [39]. These abilities are enabled by various domains of the DoD force development paradigm (i.e., DOTMLPF-P[2]), of which doctrine, training, and leader education are key elements. Activities in these

[2]The DOTMLPF-P domains are doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy.

domains include exercises and wargames. As the CNI strategy [39] points out:

> Exercises and war-games are training and assessment tools for unit readiness and CNI implementation. . .Improved modeling and simulation (M&S), and test and evaluation (T&E) facilities can increase vulnerability assessment fidelity.

Russia's annexation of Crimea (2014) and invasion of Ukraine (2022–), China's strategic breakout (2021–), Iran's pursuit of highly enriched uranium (HEU) stockpiles (ca. 2010–), and North Korea's persistent advancement of nuclear weapons and weapon delivery technologies (2006–) only serve to underscore the importance of developing tools and methods that aide operational planning, nuclear targeting, and future force development efforts vis-á-vis nuclear vulnerability and survivability.

Accordingly, two sponsor organizations within the DoD seek a method that permits SOSVA in nuclear weapon environments. The development and demonstration of NuSCAP presents a viable solution to address this desire by providing a capabilities-based analytic method for SOSs exposed to prompt nuclear weapon environments. The NuSCAP method and application allows the DoD to understand SOS vulnerabilities and identify critical technologies, components, and systems for T&E in support of developing the future Joint Force. In these ways, the Joint Force is better equipped to exploit its resiliency to nuclear threats, develop doctrine to fight and win in those environments, and stand as a credible deterrent against both conventional and nuclear aggression.

1.2 Issues Addressed in this Dissertation

The chapters that follow address the NuSCAP method development, composition of Python packages that enable automation of analyses using the method (i.e., the NuSCAP application), and a case-study demonstration. The following chapters also address ancillary discoveries made during the development and implementation of NuSCAP. These include initial data requirements, sources of those data, challenges inherent to the development and execution of this type of analysis, and significant lessons learned throughout the research and development processes.

1.3 Advancements in the Field

The development and demonstration of the NuSCAP method and application advance the fields of nuclear engineering and vulnerability analyses in several ways.

NuSCAP provides the DoD with a method and computational application with which it may perform capability-based SOSVA for operations in nuclear weapon environments. NuSCAP was conceived primarily to study US military SOS vulnerabilities to the effects of adversary nuclear weapons on the battlefield and the consequence of execution related to the use of US or allied nuclear weapons. However, the capabilities-based SOSVA approach allows DoD analysts to employ NuSCAP for a variety of purposes not directly related to its inception. There is potential for NuSCAP's use as a supplementary targeting tool allowing military planners to assess friendly nuclear weapon effects on adversary SOS. NuSCAP may also be linked to the mission and means framework (MMF) to support large-scale, dynamic combat simulations (e.g., wargames) [10, 40–43]. Its flexible and extensible nature makes it particularly well suited to support mission-based test and evaluation (MBT&E) of prototypical equipment or equipment currently undergoing research and development—a key part of future force development executed within the Joint Capabilities Integration and Development System (JCIDS).

The methods incorporated into NuSCAP's nuclear weapon environment models and calculations are superior to those employed in the most-recent nuclear SOSVA method, the Army Unit Resiliency Analysis (AURA). In lieu of the somewhat limited Nuclear Damage Assessment Computer Code (NUDACC) used in AURA, NuSCAP employs the United States Strategic Command's (USSTRATCOM) Probability of Damage Calculator (PDCALC) version 8.2 along with Los Alamos National Laboratory's (LANL) Simple Nuclear Effects Calculator (SNEC). These two codes are widely accepted by experts in the nuclear weapon effects field and are included in NuSCAP because of their renown and portability. The PDCALC algorithms also permit the use of VNTK, 2-VNTK, and G-VN physical vulnerability metrics [17, 44] that military analysts, weaponeers, and targeteers rely on daily to hold strategic targets at risk and determine consequence of execution for nuclear operations. These standard metrics along with the use of the military grid reference system (MGRS) [45, chapter 3] location format allow NuSCAP to share a common vernacular with those who may rely on this new tool to perform their jobs.

Neutral particle transport calculations in NuSCAP are performed via the MCNP code. As discussed in §2.2, MCNP6 is a highly regarded and extensively benchmarked industry standard for neutral particle radiation transport calculations with applications ranging from radiation shielding and nuclear medicine to radiological dispersal device (RDD) and nuclear weapon effects modeling. As such, the fidelity of ionizing radiation environment calculations from a nuclear weapon detonation in NuSCAP are only limited in practicality by the availability of high-performance computational resources and the accuracy of environmental and target model inputs to the scenario. (Several of these limitations are discussed in chapter 6.) Analyses of nuclear radiation environments in NuSCAP are not limited to coarse 50 m $\times$ 50 m grids as with AURA. Quantities of interest

may be calculated down to the individual component level as permitted by model fidelity and available computational resources. Using the MCNP code, these radiation environments are calculated using detailed neutron and photon energy spectra representative of those emanating from actual nuclear weapon detonations rather than previous, generic analytical solutions based on broad categories of weapons. Additionally, phase space conditions such as 3-D terrain effects, other intermittent shielding objects (e.g., vehicles or buildings), and atmospheric variations (e.g., humidity, pollution, density gradients) are possible in the model as opposed to the fixed density, dry-air attenuation calculations given by AURA. The NuSCAP demonstration included in this work shows rudimentary application of the MCNP code to the nuclear SOSVA problem. Further discussion in §2.2 articulates the current state of high-fidelity unstructured mesh capabilities that may be included in future NuSCAP studies and use cases (see §6.3.2).

The flexible and extensible Python script and JSON data files enable the NuSCAP user to develop scenarios and SOS models of whatever practical complexity is needed to answer a particular SOSVA question. Accepted weapon parameters include explosive yields ranging from 0.1 kilotons of TNT (kt) to 10 megatons of TNT (Mt), heights of burst (HOB) from 0 to 85.999 km, any neutron and photon source spectra compatible with the MCNP code, and any actual ground zero (AGZ) location with a valid MGRS grid. Unlike NUDACC, in NuSCAP there is no requirement for HOB to remain a function of yield, nor is it necessarily tied to the scaled "fallout-free" HOB (FFHOB). Similar to AGZ, the physical locations of any target element (i.e., a component, subsystem, or system) may be included as long as it is a location for which valid MGRS data exists. The SOS composition is accomplished by way of directed, acyclic graphs (DAG)—sometimes referred to as trees—that may be constructed in any conceivable arrangement and extent so long as initial connectivity exists by at least one path between the terminal vertices of the SOS graph. This permits the accurate representation of complex parallel and serial SOS architectures. The user may also choose to represent 3-D terrain and various atmospheric conditions as in [46]. Three-dimensional representations of local topography, soil composition, and air composition possible with the MCNP code enable future expansion of NuSCAP to capture nuanced changes in nuclear radiation environments not present in previous methods (e.g., AURA). Effects of sky shine, ground shine, and shielding by intervening terrain may be assessed in this way. Likewise, the use of the MCNP code allows the representation of critical elements (both hardware and personnel) in and around vehicles and fortifications that no longer assume a standard radiation protection factor as does NUDACC. Finally, this structure enables the assessment of each model element against any of the available nuclear weapon environment models. If a measured dysfunction threshold exists (or may exist) for a given element in a specified environment, the NuSCAP application structure permits the evaluation. The environments considered in NuSCAP include, but need not be limited to: peak static overpressure,

peak dynamic pressure (and maximum windspeed), thermal fluence, total ionizing radiation dose, neutron dose, neutron fluence, photon (gamma ray) dose, peak photon (gamma ray) dose rate, and VNTK-based probability of damage (PD). Because of this flexible and extensible construction, the NuSCAP method and application need not be limited to military applications. It may also be considered a tool for emergency response planning and municipal infrastructure resilience analysis problems.

Visualization of NetworkX graph analysis methods employed in NuSCAP lends itself well to reducing the tendency of user error in NuSCAP when compared with historic SOSVA methods. The conventional weapon SOSVA method, the System Capabilities Analytic Process (SCAP), relies up the derivation and long-hand input of extensive algebraic expressions to represent complex system structures. Conversely, in NuSCAP, the user constructs and views a graphical representation of each system (and the entire SOS) prior to execution of the SOSVA methods. The graphs used in NuSCAP analyses are constructed by the use of simple ordered pairs that represent the source vertex and terminus vertex, respectively. Thus, the user need not be concerned with troubleshooting a lengthy aggregation of product-sum expressions. Rather, the user is able to build out the system design and visually validate its accuracy against functional block diagrams of the actual item being represented in a simple connect-the-dots manner.

Summarily, NuSCAP advances the present state of the art in SOSVA by providing a flexible and extensible application with which analysts can explore SOS vulnerabilities within the nuclear weapon effects phase space from a quantifiable, capabilities-based perspective. NuSCAP extends the applicability of the SCAP method to nuclear weapon effects studies; and, it exceeds the capabilities of legacy nuclear survivability models (i.e., AURA) by employing high-fidelity neutral particle transport calculations, industry-standard air blast models, and thermal fluence calculations in a manner that reduces user error while providing customer-focused capabilities-based results.

1.4 Research Questions

Pursuant to the goals and objectives of this research effort, several key questions are investigated:

1. How might one assess the vulnerability of a SOS to nuclear weapon environments?
2. What tools and skills are required to conduct the nuclear SOSVA?
3. What are the minimum requisite data to support the analysis of a specified SOS?
4. What are the challenges and roadblocks to such an analysis?

1.5 Outline of this Dissertation

The remainder of the dissertation is divided into five additional chapters with supporting data found in seven appendices. A brief description of each major division of the dissertation is provided in the following subsections.

1.5.1 Chapter 2: Literature Survey

This chapter presents a survey of prior work pertinent to this effort. Specific emphasis is given to historic and contemporary SOSVA methods, their capabilities vis-à-vis nuclear weapons effects, and their limitations. This chapter also discusses literature regarding use of the MCNP code as a tool for nuclear weapon effects modeling along with the use of graph analysis in SOSVA studies.

1.5.2 Chapter 3: NuSCAP Method

This chapter elucidates the development of the NuSCAP method, its basis in conventional weapon SOSVA practices, the steps required to develop a viable SOSVA method for nuclear weapon environments, and the development processes required for SOS models and analytical scenarios. Graph analysis implementation, requisite data, and data sources are also covered.

1.5.3 Chapter 4: NuSCAP Application

This chapter explicates the production and testing of the NuSCAP Python application. Emphasis is given to Python package development, user generated input data files, and automation of external software. External software includes SNEC, PDCALC, and the MCNP code. A brief user's guide is provided that covers execution of the NuSCAP application, interpretation of results, and dealing with warnings, errors, and troubleshooting.

1.5.4 Chapter 5: Case Study Results

This chapter details a sponsor-directed case study demonstration of the NuSCAP method and application. System of systems, system, and analytical scenario data file production is covered along with observations during the execution of three separate scenarios. The results of those three scenarios are presented along with discussion of their practical relevance to an operational commander.

1.5.5 Chapter 6: Concluding Remarks

This chapter summarizes the accomplishments and contributions of this work. Desirable directions for future research and application are discussed. This chapter also describes practical challenges and lessons learned during the development and implementation of NuSCAP.

1.5.6 Appendix A: Figures

Figures supporting the body of the dissertation are contained in appendix A.

1.5.7 Appendix B: Tables

Tabular data supporting the body of the dissertation are contained in appendix B.

1.5.8 Appendix C: Graph Traversal Verification

A series of graph representations of basic system architectures is presented. Algebraic and NetworkX [47] graph traversal examples are provided to demonstrate equivalency between SCAP's binary solutions and NuSCAP's Boolean solutions.

1.5.9 Appendix D: NuSCAP Python Application

This appendix provides the NuSCAP application Python code packages, computational environment files, example data files required for executing SOSVA using NuSCAP, and examples of SNEC input, batch, and output files.

1.5.10 Appendix E: Unit Testing Modules and Data

All NuSCAP application pytest unit testing modules and supporting data files are provided.

1.5.11 Appendix F: Case Study Data

This appendix contains all user-generated input files used to perform the case study discussed in chapter 5. All NuSCAP output reports and graph images produced during the SOSVA are included. User-generated images of the SOS graph and each individual system graph prior to analyses are provided for reference.

1.5.12 Appendix G: Operationally Relevant Application

Details of current operational relevance pertaining to the development and application of NuSCAP are provided in a limited-distribution appendix to this work.

Chapter 2

Literature Survey

The ultimate responsibility for our nation's policy rests on its citizens and they can discharge such responsibilities wisely only if they are informed.

HENRY DEWOLF SMYTH

This chapter consists of a survey of literature pertaining to the goals of this work. Topics covered include: recent DoD SOSVA methods, their capabilities, and their noteworthy shortcomings, specifically with regard to treatment of nuclear weapon environments and effects; work involving the MCNP code for nuclear weapon effects studies; and the application of graph theory to SOSVA studies.

An earnest effort to thoroughly canvas all available literature was given in each topic area. With the inexhaustible resources provided by the internet, the choice was made to focus strictly on the topics as they are presented in the preceding paragraph. Those articles and technical reports whose topics did not fall squarely within the bounds of these areas are left to the next researcher for consideration.

2.1 Recent Department of Defense SOSVA Methods

Since the early 20th century, the US military has invested a great deal to understand the effects of weapons on various targets. By the 1950s, scientists and engineers unified vulnerability and lethality studies into a single discipline [48]. However, conventional kinetic threats to personnel and equipment provided the principal focus of the field. With the exception of the Residual Combat Capability (RCC) method (later known as the Army Unit Resiliency Analysis methodology), the vulnerability of personnel and equipment to nuclear weapon effects is treated as a separate topic entirely—a paradigm that persists today.

By the 1990s, with the integration of digital computer networks on the battlefield, military leaders, analysts, and strategists became concerned with the cumulative effect the loss of one element or system produces on the larger SOS. Over the past several decades, the US Army Research Laboratory (ARL) and others have proposed and implemented several SOSVA methods [10, 49–55]. These have focused primarily on conventional, kinetic threats with some limited application to CBRN weapons [49, 56, 57]. This section explores three DoD SOSVA methods: the RCC method (later AURA), the System of Systems Survivability Simulation (S4), and the System Capabilities Analytic Process.

2.1.1 The Residual Combat Capability (RCC) and Army Unit Resiliency Analysis (AURA) Methods

In the late 1970s, the US Army undertook an effort known as the Theater Nuclear Force Survivability (TNF/S) study. The aim of TNF/S was to determine the residual combat capability of a force after encountering a range of hostile actions. The BDM Corporation produced a unit-level model named Combat Capability Degradation (CCD) that built on common survivability, lethality, and vulnerability (SLV) concepts by adding the recognition of combat capabilities. The BDM Corporation did not deliver the proprietary developmental code base used to produce the CCD method, causing the Army to develop an independent code with which CCD analyses could be produced. This program became known as the RCC code. First reported in 1979, the RCC method and code is the earliest unit-level vulnerability analysis tools developed by the US Army's Ballistic Research Laboratory (now ARL) [58]. While the authors do not explicitly call RCC a SOSVA method or tool, RCC contains many hallmarks of such a tool, as described in the following paragraphs.

The code enables an analyst to construct a unit of personnel and equipment with great flexibility to include location, skill level, cross-training, and reconstitution speed. Each unit is defined by the user in one of several defensive postures with a corresponding Required Kill Criterion (RKC) for conventional, chemical, and nuclear threats. Conventional lethality is determined based on the type of explosive weapon delivered, the height of burst, unit defensive posture, and corresponding RKC for the weapon type of interest. Bi-axial weapon delivery error is generated for each round by normally distributed random number draws to generate an actual delivery point. Nuclear lethality parameters are generated by NUDACC. The RCC code only evaluates unit elements against "blast overturn [dynamic pressure], EMP [electromagnetic pulse, type not specified], and neutron-fluence" [58].

As the Army continued to develop the capabilities and applications of the RCC code to quantify the

expected effectiveness of key units during a European Cold War scenario, developers renamed RCC the AURA method and code in the early 1980s [59]. The operational versions of AURA consist of an amalgamation of numerous modules, algorithms, and data sources aimed at quantifying a military unit's ability to perform a series of continual missions after one or more insults by conventional, chemical, and/or nuclear munitions [60]. The AURA code underwent several iterations of upgrades through the 1980s and 1990s with reports indicating its use as late as 2001 [60, 61], but there is no indication that AURA is presently maintained or used by the nuclear weapon effects or survivability, lethality, and vulnerability analysis (SLVA) communities.

The AURA method and code quantify the ability of a unit to perform key tasks in support of a specified mission. This is accomplished by mathematically evaluating the survival of a prescribed combination of personnel and equipment following insult by one or more threat weapons. While the computational procedure is not well defined in the available literature, the AURA code compares the RKC for each element of a unit with the magnitude of conventional, chemical, or nuclear weapon effects at the location of the element. Based on that comparison, a probability of kill is calculated for that interaction and a "dead" or "alive" result is determined by AURA's deterministic or stochastic modes for each element considered [60]. Elements killed by the insult are removed from the model, and the effectiveness (i.e., ability of the unit to perform one or more tasks) is accordingly limited by application of so-called link effectiveness curves [60]. The link effectiveness curves are based on the assumption that a minimum number of assets (personnel and/or equipment) are required to complete a task. Furthermore, AURA assumes adding assets to the task may increase the unit's effectiveness (quality or speed) at that task, but above a certain maximum number, no benefit is gained. If the assets available to complete a task fall below a minimum allowable quantity, the task cannot be performed [60]. According to the link effectiveness curves, the effectiveness of the unit increases monotonically between zero effectiveness and full effectiveness. An AURA analysis iterates through this process for a number of mission-related tasks and reports the unit's ability to perform. Between iterations, an asset reallocation and optimization algorithm attempts to provide the unit with assets necessary to perform the most critical mission tasks and continue.

Despite AURA's many attributes—it successfully quantifies the resiliency (i.e., lack of vulnerability) of an interrelated military unit (i.e., battalion or smaller) following an attack to include repair, reconstitution, and application of cross-training metrics to reinforce manpower losses—it also suffers from several inherent limitations with regard to nuclear engagements. These limitations are discussed in the following subsections.

2.1.1.1 Weapon Effects Resolution

For a unit within range of a nuclear weapon detonation, NUDACC overlays the unit with a uniform 50 m $\times$ 50 m square grid [62]. All nuclear weapon environments are measured at the centroid of each grid square and are then uniformly applied to all elements of the unit within that square region [62]. Modern approaches included in NuSCAP permit calculation of nuclear weapon environments at the point of interest for each phenomenon considered. Further discussion of these techniques follow in §2.2.

2.1.1.2 Particle Transport Methods

The nuclear radiation particle transport method employed within AURA by NUDACC relies on simple attenuation calculations applied to one of thirteen generic weapon source terms [60, 62–64]. Individual particles are not transported, rather the general flux equation for an isotropic point source is adapted to calculate neutron and photon dose contributions and the neutron fluence from each of the thirteen available weapon types [64].

The general form of the uncollided neutron fluence equation for a nuclear weapon detonation in a static transport medium (i.e., air) is

$$\Phi_n(W, r) = \frac{k \cdot W \cdot e^{(-N_{\text{Air}}\sigma_{t,\text{Air}}r)}}{4\pi r^2}, \tag{2.1}$$

where k is the neutron yield of the weapon [neutrons·kt^{-1}], W is the weapon's explosive yield [kt], N_{Air} is the number density of air molecules $\left[\text{cm}^{-3}\right]$, $\sigma_{t,\text{Air}}$ is the total microscopic interaction cross section [b], and r is the radial distance (i.e., slant range) from the point of the nuclear detonation to the target [cm]. For most nuclear weapons of interest, $k \approx 6 \times 10^{23}$ neutrons $\cdot$ kt^{-1} [65, table 8.5]. Applying the constraints of neutron interactions in dry air at sea level gives

$$\Phi_n(W, r) = 4.77 \times 10^{22} \frac{W \cdot e^{\left(-2.5 \times 10^{-4} r\right)}}{r^2}. \tag{2.2}$$

In AURA [60, p. 136], the neutron fluence equation is reported as

$$\Phi_n(W, DS) = 4.82 \times 10^{12} \frac{W \cdot e^{(-4.44)} \cdot (DS)}{(DS)^2}, \tag{2.3}$$

where DS is defined as the distance measured along flat ground between AGZ and the target in kilometers. The use of ground distance rather than slant range here is in error. Referring to the AURA and NUDACC source document [63, equation (1) and table I], one finds the original form of the equation

$$\Phi_n(W, r) = 4.82 \times 10^{12} \frac{W \cdot e^{(-4.44r)}}{r^2}, \tag{2.4}$$

which is the version the author hopes AURA actually employed. In this case, r is given in kilometers. Allowing for the differences between the calculated total cross section in equation (2.2) and the unspecified cross section (purely absorption, perhaps) in equation (2.4), one finds generally good agreement.

While this rudimentary method provides a rapidly attainable flat-field estimate of neutron fluence (the peak photon dose rate is similarly treated), a number of other factors complicate neutral particle transport from the burst to the target. Among these are atmospheric conditions, intervening terrain, and the complex nature of neutral particles interactions with matter. Neutral particle transport in AURA does not deal with these factors. Both modern Monte Carlo and discrete ordinates transport methods allow a much more-rigorous treatment of the transport problem. Additional detail is given in §2.2.

2.1.1.3 Radiation Transmission Factors

Regarding both photon and neutron radiation, the AURA and NUDACC codes employ five radiation transmission factors of a general nature based solely on the type of vehicle or fortification in which unit personnel are located: exposed, open vehicle, foxhole, armored personnel carrier, and tank. While user inputs can modify these transmission factors and introduce new or customized vehicles, the transmission factor values pertain only to the type of incident radiation and the protective posture of the personnel. No distinction is made for location in the vehicle or fortification. A crew member shielded from photons by a vehicle's windshield is assessed the same as another crew member shielded by the vehicle's iron engine block. Likewise, a crew member shielded from neutrons by fuel or ammunition is treated equally to the crew member who is shielded only by a thin, aluminum door panel. By introducing 3-D computer-aided design (CAD) models into unstructured mesh neutral particle transport, these transmission factors (and the radiation protection factors derived therefrom) need not be uniform for all crew members. Work by Spencer and Goorley [66, 67] discussed in §2.2 provides additional detail on this topic.

2.1.1.4 Nuclear Detonation Parameters

In AURA (NUDACC), nuclear weapon yields are limited to the range of 0.1 kilotons of TNT (kt) to 500 kt, only. The HOB used in each calculation,

$$\mathrm{HOB}(W) = 60 \times W^{\frac{1}{3}}, \tag{2.5}$$

is that at which optimum blast overpressure is achieved for the specified yield scaled according to the FFHOB for a 1 kt detonation [60, p. 136]. Yield restrictions in NUDACC limit the HOB envelope to include options from 28 m to 500 m, only.

The AURA and NUDACC codes allow only the selection of a standard nuclear weapon or an enhanced radiation weapon (specified by inputting two yield values). This limits the ability of the user or analyst to customize radiation outputs from the nuclear detonation (i.e., leakage spectra) in order to determine case-specific vulnerabilities of the element in question. By employing the MCNP code for neutral particle transport, any of the available neutron and photon nuclear weapon leakage spectra [65, 68–72] may be modeled at the discretion of the analyst to provide additional model fidelity.

2.1.1.5 Terrain and Weather Effects

Atmospheric and terrain effects receive only modest treatment by AURA and NUDACC. Only thermal x-ray fluence calculations consider atmospheric conditions (i.e., visibility). Similarly, the only mention of terrain effects is the reduced radiation transmission factors given for personnel in foxholes. Without mention, even the effects of atmospheric density at various elevations and altitudes is seemingly neglected by the AURA and NUDACC methods. Three-dimensional terrain models that include the effects of weather and pollutants have been employed by McClanahan [46] in studies investigating neutral particle transport resulting from nuclear weapon detonations.

2.1.1.6 Equipment Damage Criteria

Sheroke, et al. [60] points out

> The NUDACC databse [sic] has not been updated in a number of years; consequently, it lacks data on many of the newer pieces of equipment.

No follow-on reports indicate that vulnerability criteria for contemporary or modern equipment were added to AURA's repertoire prior to its last use. One may assume kill criteria that were outdated in 1990 do not reflect the current technological complexity of DoD assets subject to analysis by this work. However, in absence of full-scale nuclear weapon testing, gleaning and acquiring accurate failure threshold data for any modern equipment presents a significant challenge—one discussed in §6.2.1.

2.1.2 System of Systems Survivability Simulation (S4)

In 2006, ARL reported developing a SLVA method to assess the dynamic effects of decision-making processes on a SOS inherently dependent on networked information sharing [52]. The S4 permits discrete, time-dependent SLVA in a force-on-force combat scenario [52]. Vulnerability simulations conducted by S4 rely on the Modular UNIX®-based Vulnerability Estimation Suite (MUVES) model developed by ARL in the late 1980s [52, 53, 73]. The MUVES model focuses primarily on modeling armored vehicle vulnerability to conventional, kinetic threats. Nuclear weapon effects are omitted entirely from all versions of the MUVES model; ergo, they are not considered by S4 [74].

The S4 project (and its follow-on studies) [50, 52–55, 75] demonstrated the Army's first formal "system-of-systems" vulnerability analyses method that emphasized human factors integration to quantify mission success. The 2009 use of S4 in a kinetic vulnerability study also represents one of the first reported high-fidelity (3-D CAD using structured mesh) vulnerability analyses of a modern combat vehicle [53].

While S4 addresses kinetic survivability of combat vehicles in a SOS, one notes the emphasis is on dynamic survivability of a force based on decision-making and information flow framed by quasi-dynamic doctrine. This method does not effectively support capabilities-based analyses of a lower-echelon, combat SOS that assumes application of static doctrine to determine its vulnerability to a particular ordnance (i.e., nuclear weapons). Instead, it is more well-suited for use in dynamic, force-on-force combat simulations.

2.1.3 System Capabilities Analytic Process (SCAP)

The ARL's SCAP represents the state-of-the-art in military SOSVA methods. Developed by ARL in 2009, the SCAP method employs quantitative, logical links between the functional states of a system's components and its military capabilities [10, 40]. In this case, the "system" may represent anything from a single combat vehicle to a SOS composed of many individual combat platforms with varying purposes [10].

The SCAP relies on the use of a functional skeleton (FS) to map the system's capabilities to its components and subsystems. All component types are considered, including hardware, software, and personnel at various indenture levels (e.g., element, component, assembly, subsystem) [10]. The FS is manifest as a multi-use tool composed in-part of a deactivation diagram that supports criticality analysis and determination of elemental function or dysfunction based on damage sustained in a combat scenario. In this context, criticality analysis is the process undertaken to determine which components of a subsystem, system, or SOS are required to achieve specific capabilities and how failure of those elements affects the operation of the greater whole [48].

An exemplar FS is shown in figure A.1[1].

For a SOS, SCAP relates the various constituent systems to one another based on the possession of shared capabilities [10]. This approach permits the analyst to understand the effect of losing a critically important element in one or more systems on the residual capabilities of the entire SOS. An example of this relationship is shown in Agan's juxtaposition of an unmanned aerial vehicle (UAV) observing artillery fire from a self-propelled howitzer in figure A.2.

SCAP analyses produce binary quantification of element functionality: namely "functional" or "dysfunctional." Functional elements are defined as those that continue to perform as intended, whereas dysfunctional elements exhibit degraded or null performance [10]. A binary determination of system functionality results from a mathematical model of the functional skeleton that assigns a score of unity to functional elements, components, subsystems, etc. Conversely, those determined to be dysfunctional are scored zero. Causes of dysfunction are not strictly defined in [10], but it is implicit that these result from kinetic damage from conventional munitions. Damage is induced by calculating kinetic energy deposition by a munition onto a physical element of a system [77]. If the magnitude of kinetic energy deposited exceeds a pre-set threshold for that element, it is deemed dysfunctional.

The aggregate functionality of subsystems or systems is calculated depending upon their manner of construction. Each element is scored according to its functionality, and an algebraic expression is composed to represent the linear and parallel relationships between the various elements. Elements are considered parts of trees where they exist in some combination of serial and parallel relationships. The functionality A of tree j composed of serial elements i is

$$A_j = \prod_{i=1}^{n} E_i, \tag{2.6}$$

[10, equation (2)] where E_i is the functionality of the individual element.

The aggregate functionality A of tree j composed of parallel elements i is

$$A_j = 1 - \prod_{i=1}^{n} (1 - B_i), \tag{2.7}$$

[10, equation (3)] where B_i is the functionality of the individual branch of the functional tree. Branches may be single elements or a collection of elements in parallel or serial relationships.

[1]Despite living in an era of computational power and ready access to information at heretofore unimaginable scales, recent (since 2020) graduate and post-graduate students have been unable to follow long-held, rudimentary formatting instructions practiced by the University of Tennessee. To aide the most well-educated amongst us with this Herculean undertaking of standard typesetting practices, a recent Associate Dean of the Graduate School directed the institution to establish simpler formatting guidelines [76]. A result of this abnormal and unnecessary simplification is the creation of non-standard and impractical, dedicated appendices for all figures (appendix A) and tables (appendix B) that would otherwise appear in the body and flow of this document.

These aggregate measures of functionality are stored as vectors representing the various components, subsystems, systems, functions, and capabilities within the functional skeleton. Based on the design of the system or SOS, these vectors undergo arithmetic manipulation to determine the resultant SOS functionality and residual capabilities [40].

Consider the FS in figure A.1. The rim, wheel, and hub of the wheel subsystem have taken damage and are dysfunctional. Because of the subsystem's design, these damaged components have rendered the wheel dysfunctional. Thus, the right, third wheel cannot support the weight of the tank (a function). Supporting the weight of the tank is a function required to enable the tank to travel off-road (a capability). Because the weight is not supported, the tank cannot travel off-road. In a functional-but-degraded SOS, residual capabilities are ascertained by an analyst's inspection of the mathematical FS model. This action is represented by the operator λ in [10]. An example is given in figure A.3 where two tanks must travel together on a road in order to meet the commander's intent of unit cohesion during a tactical road march mission. Because the second (right) tank has taken damage that limits its capability to travel on roads to a top speed of 30 miles per hour (mph), the SOS (i.e., a tank formation) is limited to traveling at a top speed of only 30 mph.

To date, ARL reports applying SCAP to only two specific case studies. The first analyzes a pre-production combat vehicle against basic mission requirements for production and acquisition [78]. This document reports residual capabilities of the test vehicle after a notional conventional weapon attack as compared with Army requirements. The second furthers SCAP application by employing it in the assessment of battlefield obscurant system performance during a combined-arms, force-on-force simulation [41]. No available SCAP documents report including or considering CBRN weapon environments or effects. Much like S4, SCAP deals only with conventional, kinetic threats to personnel and equipment.

2.2 The Monte Carlo N-Particle® (MCNP®) Code in Nuclear Weapon Effects Studies

The MCNP code is renowned for its utility and accuracy throughout the radiation transport community. Among its many applications, the MCNP code serves as a well-respected tool in modeling radiation emitted from nuclear weapon sources, the transport of those emissions through space and time, and the effect of the emissions on people and equipment.

2.2.1 Background of the MCNP Code

There are numerous radiation transport computational methods available, and even within the Monte Carlo method, there are many purveyors of Monte Carlo transport software. It is the MCNP code's extensive history of verification and validation (V&V) work and the unyielding reliance on it by the nuclear weapon effects and survivability communities that underpin its use in this work. The would-be analyst should note this is but one approach of many as [46] discusses in some detail.

The MCNP code traces its roots to correspondence between John von Neumann and LANL Theoretical Division leader Robert Richtmyer in 1947 wherein von Neuman proposes the use of statistical methods to solve neutron diffusion and multiplication problems. In the same year, Enrico Fermi developed the FERMIAC11 mechanical computer that used Monte Carlo methods to trace neutron movements in fissionable material [79]. Since these seminal cases, LANL has continued to develop Monte Carlo methods and computer applications for radiation transport calculations. Goorley, et al. [79] provides a detailed recount of these methods through MCNP6 Beta 2. Currently, the state-of-the-art Monte Carlo code is MCNP6.3, a code capable of tracking some 37 diverse particle types over a wide range of energies in myriad materials using both constructive solid geometry (CSG) and unstructured mesh (UM) geometry representations derived from detailed CAD representations along with many other new features and notable improvements over previous versions outlined specifically in [80].

Scientists and engineers have employed the MCNP code to model radiation transport for myriad reasons since its availability in 1977. Because of the code's extensive benchmarking and V&V, it enjoys notable renown in the nuclear engineering, nuclear physics, and radiation health physics communities. McClanahan notes in his recent work on the matter [46] that despite the existence of a number of competing Monte Carlo radiation transport codes, the MCNP code maintains a certain ubiquity in the radiation transport community. No fewer than 184 publications by myriad scientists from three national laboratories and members of industry attest to validity of results from the MCNP code in a wide variety of applications [81]. These include the V&V of the latest version, MCNP6.3 [82] that currently awaits public release. Furthermore, a November 2022 study [83] reports that graduate students at no fewer than 156 universities worldwide have relied upon the MCNP code in various versions to produce at least 752 theses and 861 dissertations.

Moreover, [84] notes the MCNP code is considered the "gold standard code for radiation transport" in the nuclear weapon effects community. Of its many applications, various releases of the MCNP code are found in copious studies modeling the transport of radiation released during and subsequent to nuclear weapon detonations. An exhaustive review of these studies is well beyond the scope of this work, but several

of those germane to this work are discussed in the following subsections. These fall into three general categories: modeling radiation environments following nuclear detonations in terrain of varying complexity, studies specifically focused on radiation protection factors provided by military vehicles, and work focused on survivability/lethality because of nuclear weapon effects. The discussion that follows seeks to demonstrate the applicability of the MCNP code to studying the prompt radiation environments military personnel and equipment are likely to experience on a nuclear battlefield.

2.2.2 Post-detonation Radiation Transport Studies

Over the past two decades, the possibility of a nuclear detonation from terrorists and/or state-level adversaries has garnered much attention in the literature. Accordingly, a number of publications address modeling and simulating both the prompt and delayed radiation environments resulting from such an event. These studies generally fall into two broad categories: general environmental studies—those that attempt to understand the radiation environments resulting from a nuclear detonation in a generic atmosphere or on a typical earthen surface; and complex environmental studies–those that explore radiation transport through urban and other perturbed environments.

2.2.2.1 General Environments

Because of the depth of study, both via calculation and by analysis of empirical data from above ground nuclear weapon tests, the use of the MCNP code to explore general environments is limited. However, in recent literature, four studies have attempted to further our understanding of the general nuclear detonation environment using the MCNP code.

White [85], Nichols [86], and Vanden Raadt [87] each explore atmospheric attenuation of various representative nuclear weapon source spectra. White and Nichols study attenuated and down-scattered source term to determine expected doses and/or dose rates for exposed equipment at various ranges and altitudes. Both studies note that the results produced by the MCNP code agree well with first-order analytical approximations made during the work. Vanden Raadt's investigation attempts to determine the effects of prompt radiation on the development of blast waves in nuclear detonations.

Kruger's work [88] elucidates the effect of gamma shadow from external warhead components on the generation of EMP resulting from high-altitude detonations. His MACSYNC code uses MCNP5 calculations to transport prompt gamma photons, scattered photons, and Compton electrons resulting from a high-altitude nuclear explosion (HANE) to determine the resultant EMP.

2.2.2.2 Complex Urban Environments

With concern over potential acts of terrorism involving improvised nuclear devices (IND) and/or RDD, development of complex models to understand the effects of these weapons in urban terrain received much attention in the late 2000s and 2010s. Many of these studies relied on the MCNP code to provide radiation transport calculations in support of their research goals [46, 84, 89–100].

Noteworthy among these studies are those in recent years by McClanahan, et al. In these studies, the MCNP code and its UM methods are used to explore detailed, city-scale models. In [100], McClanahan, et al. point out that MCNP6.2 UM calculations agree well with measured dose rates recorded by site surveyors at Hiroshima and Nagasaki following the nuclear detonations in World War II. This verification study underpins the methods given in [46, 99] that seek to predict nuclide transmutation and activation following nuclear detonations in complex urban terrain. The ACTIUM toolkit discussed in these studies relies on MCNP6.2 transport calculations to provide the resultant incident source terms on buildings, their contents, and their surroundings.

Likewise, [97] discusses the use MCNP5, v.1.60 and its CSG modeling capability to calculate doses to people in the city of Washington, DC following the detonation of a 10 kt fission weapon at ground level. In this study, Kramer, et al. calculate that urban building occupants in this scenario may receive only 17%–21% of the free-field radiation dose.

It is of note that the studies by McClanahan, et al. [46, p. 49–59] and Kramer, et al. [97, p. 22] discuss the use of general building material definitions that may limit the accuracy of results. However, [99] gives the first treatise on a measured approach to determining combined material contents of the building and its contents.

2.2.3 Radiation Protection Factor (RPF) Studies

During the Cold War, the United States government conducted a great deal of research to understand the protection its military vehicles afforded their crew in nuclear war scenarios. However, as the Cold War drew to a close in the early 1990s, radiation protection factor studies saw decline along with full-scale nuclear weapon tests and the American concern with nuclear war in general. In the subsequent years, the DoD replaced many Cold War-era military systems with new, more technologically advanced, and arguably more lethal successors. As these systems were developed and fielded, a much lesser degree of emphasis was placed on understanding how modern combat platforms shielded their crews from nuclear radiation while they experienced a marked improvement in kinetic protection. This is especially evident in the rapid fielding initiatives undertaken

during the Global War on Terrorism (GWOT) which saw the widespread adoption first, of "hillbilly armor" (i.e., steel plates and sandbags), then of V-shaped vehicle hulls, followed by slat armor, and even explosive reactive armor (ERA) tile systems. None of these were initially evaluated against radioactive threats because of the immediate demands to meet extant conventional threats from improvised explosive devices (IED), explosively formed projectiles (EFP), and man-portable anti-armor weapons, such as the ubiquitous RPG-7.

Following the release of radioactive material from the Fukushima Daiichi nuclear power plant in 2011, the DoD quickly sought to provide humanitarian assistance to those affected by the preceding earthquake and tsunami. It became immediately evident that decision makers would be constrained by a significant knowledge gap: no one could quantify the level of radiation protection afforded to US personnel by their modern equipment. From this striking revelation, along with the abiding concerns regarding INDs and RDDs, came a rapid resurgence in RPF studies. The MCNP code, particularly MCNP6.1 and MCNP6.2 were used extensively in this space [66, 67, 96, 101–124].

2.2.3.1 The MCNP6.1 RPF V&V Campaign

As a result of the DoD's RPF knowledge gap following Operation Tomodachi [125], DTRA and undertook an effort inspired by RPF studies produced in the Cold War era with the goal of understanding capability of the modern US military vehicle fleet to protect DoD members from radiological and nuclear threats. The first step taken in this effort is V&V of the calculations produced by the radiation transport code chosen by the sponsors. The Defense Technical Information Center (DTIC) determined that the MCNP code provided the best overall radiation transport capabilities when compared with the Monte Carlo Adjoint Shielding (MASH) code and the Vehicle Code System (VCS) over the course of several decades [102]. MCNP6.1 serves as the standard method of calculation throughout the RPF V&V campaign studies with the exceptions of the complementary work performed by Decker [102] and Erwin [103] early in the campaign. Both [102, 103] used MCNP6 in work that was underway prior to the public release of MCNP6.1 in 2013 [126]. Beginning in 2014, this body of work consists of no less than fifteen publications [102–104, 106–110, 112–114, 116, 118, 120, 123, 124] that explore the applicability of MCNP6.1 to calculating the RPFs (both neutron and photon) for simple surrogate vehicles in various configurations and diverse radiation fields.

Throughout these studies, hollow cubes constructed of aluminum frames with walls of steel plates; walls of layered steel, glass-reinforced plastic (GRP), and aluminum; and walls of layered steel, Kevlar, and aluminum were used to simulate armored vehicles of simple construction. The radiation protection factors of these surrogate vehicles were measured experimentally and calculated computationally using the MCNP code. Neutron protection factors (NPF), gamma ray protection factors (GPF), and combined RPFs were

all assessed during the campaign. Radiation sources for the experimental measurements include: ^{57}Co [103], ^{60}Co [103, 118], ^{109}Cd [103], ^{137}Cs [103, 106, 107, 109], ^{239}PuBe [102, 103, 114, 124], ^{241}AmBe [112], ^{252}Cf [108, 112], D-D fusion [102], and ^{235}U fast fission [104, 113, 124]. Computational sources included all experimental sources along with a wide variety of specified monoenergetic photon and neutron sources [120, 123]. Experimental detectors include: Bonner sphere spectrometers using both lithium iodide (LiI) [114, 124] and europium-doped lithium iodide (LiI(Eu)) [102, 104, 108, 113] scintillators, the AN/PDR-70 "Snoopy" REM meter using BF_3 active media [112], carbon-doped alumina (Al_2O_3:C) [107], high-purity germanium (HPGe) [103], lanthanum bromide (LaBr) [114, 124], sodium iodide (NaI) [103, 106], and thallium-doped sodium iodide (NaI(Tl)) [118].

Despite the diverse source spectra, detectors, and analysts, every study produced computational results that agreed within 10% of experimental and/or previously published RPF data with the exception of only one [116]. This study, which [124] attempted to combine a novel measurement of the White Sands Missile Range (WSMR) Fast Burst Reactor's (FBR) prompt spectra with previously established computational methods, yielded spurious results. The wealth of agreement in this body of work led DTRA to recommend formal acceptance of MCNP6.1 as "officially verified and validated to provide RPF estimates for vehicle surrogates" [116].

2.2.3.2 Stryker Vehicle RPF Studies

Building on the work accomplished during the extensive V&V campaign, DTRA subsequently sought to apply the MCNP code to assess the RPF of one of the US Army's newest combat platforms: the Stryker vehicle. The Stryker Family of Vehicles is built on a common eight-wheeled chassis equipped with one of several available Mission Equipment Packages [127]. In all, there are 18 variants in the Stryker Family of Vehicles [127]. Arguably the most likely of these to operate in a radiological or nuclear environment is the purpose-built Nuclear, Biological, and Chemical Reconnaissance Vehicle (NBCRV)-Stryker. Thus, DTRA selected the NBCRV as its first candidate for a full-vehicle RPF study.

An extensive body of work by Spencer and Goorley [66, 67, 117, 121, 122] investigates the RPFs of the NBCRV using a combined M&S-and-experimental approach. The team's first report [117] details the adaptation of a detailed CAD model of the NBCRV to a tetrahedral mesh model suitable for use with the MCNP6.2 UM capability using the Attila®4MC [128] workflow in conjunction with the SpaceClaim® [129] solid modeling software. Subsequently, Spencer and Goorley evaluated the NBCRV vehicle and model against a simulated fallout field represented by a regular, rectangular grid of ^{60}Co and ^{137}Cs sources [66]. The measured and calculated GPFs differ by a factor of two to three times, but a number of hypotheses are

provided for the discrepancies. Paramount among these is the existence of many unknown quantities in the NBCRV model itself. These unknown quantities include material composition and density of the Stryker's armor package as well as the contents of the void between the vehicle hull and the floor. The combination of these unknowns with questionable pre-calculated background radiation subtraction techniques lead the authors to report some warranted skepticism in the accuracy of their results. Next, Spencer and Goorley evaluate the NBCRV model against planar, monoenergetic neutron and photon sources incident normal to each side of the vehicle to document the RPFs provided by the individual sides as a function of particle type and energy [67]. The results of this study tend to exhibit better agreement with historical vehicle RPF values as shown in [122, p. 1]. In the final report [122], the NBCRV's RPF for a combined prompt fission neutron and photon spectrum is measured and calculated. Again, in this study, the measured and calculated RPFs vary by between two and six times—a behavior attributed to large uncertainties in model material specifications. Put succinctly: "The MCNP results are only as good as the assumptions in the model" [122].

In separate work conducted at the same facility as [122], Erwin constructed a rudimentary MCNP code model of the Stryker using geometry developed in SoftWare for Optimization of Radiation Detectors (SWORD) by the Naval Research Laboratory (NRL) [124]. Erwin was unable to calculate RPFs for the Stryker because of inherent geometry errors in the SWORD model leading to a greater-than-desirable number of lost particle histories in the MCNP calculations [124].

2.2.4 Vulnerability and Lethality Studies

A number of recent studies explore the ability of personnel and equipment to endure nuclear weapon radiation environments and persist through those. Yet other studies explore the ability of nuclear weapons to render certain threats ineffective. Many of these have employed the MCNP code. The following sections discuss exemplar work in each category.

2.2.4.1 Nuclear Weapon Environment Vulnerability

It is often assumed that the damage produced by nuclear weapons is devastating—to buildings, to vehicles, to equipment, and to personnel. However, it is important to those seeking to survive nuclear weapon environments that a deeper understanding is achieved in this area. To that end, the MCNP code has been applied to calculate the expected radiation dose and dose rates in nuclear weapon detonation environments. These studies may best be sub-categorized into studies involving people and those involving things.

2.2.4.1.1 Personnel Vulnerability Studies Personnel are often viewed as the element of a system most vulnerable to nuclear radiation. Thus, a number of studies have explored understanding the radiation doses to people in the vicinity of a nuclear detonation or RDD event.

A series of studies conducted at the Georgia Institute of Technology demonstrated the use of the MCNP code to evaluate the ability of three different detector types to measure internal human contamination following a RDD event [130–132]. In these studies, calculations performed using the MCNP code simulated detector responses where inhalation and distribution of various radionuclides in a laboratory is unable to be measured in a practical manner. In each case, the MCNP code produced results that agreed favorably with exemplar validation source measurements across a broad range of energies.

A number of works by Goorley, et al. report the application of MCNP calculations to city-scale models to calculate the likely dose to people near nuclear weapon detonations in urban environments [89, 90, 93, 95]. These studies are benchmarked against historical studies of Hiroshima and Nagasaki dose contours reported in post-war bombing surveys [93]. Other studies also investigate personnel vulnerability in urban nuclear weapon detonations. Kramer, et al. [97] performed MCNP calculations regarding a nuclear detonation in the Washington, DC urban area modeled as 5 m $\times$ 5 m $\times$ 5 m cubic voxels. The study reports assessment of the primary dose mechanisms and evaluation of sky shine contributions to dose. In particular, the study reports a reduction of dose by 17%–21% because of urban building shielding of prompt radiation emissions. McClanahan, et al. [100] benchmarks MCNP6.2 UM calculations against the same post-detonation bombing surveys as [93] with good agreement.

A study by Prins, et al. [98] employs the MCNP code to calculate organ-absorbed dose to the spleen, small intestine wall, bones, and lungs in a computational phantom to inform post-detonation triage and medical treatment of people in the survivable zone following a nuclear detonation. Stricklin, et al. [133] also uses MCNP urban nuclear detonation models to develop an improved approach for casualty estimation that considers the relative biological effectiveness (RBE) of neutrons in energy spectra of interest.

2.2.4.1.2 Other Vulnerability Studies While myriad studies address the vulnerability of equipment and vehicles to the blast and thermal effects of nuclear weapons, fewer are available in the literature regarding equipment vulnerability to ionizing radiation. Even fewer available publications discuss vulnerability assessments using the MCNP code. However, two publications available through DTIC discuss the MCNP code's utility in this manner.

A 1993 study by Plebuch, et al. [134] produced prompt dose rate calculations to support the Survivable Basing Technology Integration Program for Superhard Mobile Launcher Technology using the MCNP code.

In this case, the MCNP code was employed with the Air Transport of Radiation (ATR, version 5) and Defense Nuclear Agency Weapon Effects (DNAWE) codes that were used to calculate the magnitudes of other radiation environments. This study explored technologies and concepts that might allow mobile missile launchers to survive the effects of exposure to multiple nuclear weapon environments.

More recently, work by Frohling, et al. [135] relied on the MCNP code to verify various materials' photon shielding worth and electron interactions in aluminum to support the development of radiation-hardened cryogenics controllers for space hardware applications. In this case, the models allowed the researchers to understand the likelihood that the controller would operate as designed in space radiation environments. While not directly purposed toward weapon spectra survivability, similar principles are applied throughout.

2.2.4.2 Nuclear Weapon Environment Lethality

Just as it is important to understand the radiation dose and dose rates experienced by those entities seeking to survive nuclear weapon environments, it is equally important to understand the effects brought to bear on critical adversarial targets. Three salient studies utilize the MCNP code to calculate energy deposition to lethal, would-be adversarial agents.

In his 1998 work [136], Kruger explores the effect of delayed fission debris radiations on chemical and biological munitions stored in an underground bunker. Kruger's MCNP4A calculations allowed him to estimate the dose accumulated both by pooled agent on the floor of the bunker (after bursting the bulk containers) and to aerosolized agent distributed throughout the bunker. In so doing, he concludes that the delayed fission debris from a low-yield nuclear weapon detonation is a likely candidate for destruction of stored biological agents, but that dose from the same debris may be insufficient to adequately destroy chemical munitions in the same manner. Kruger's 2000 work [137] explores neutralization of biological agents in open-air or warehouse storage by the prompt radiation emitted by a low-yield nuclear weapon. From this series of MCNP4B calculations, Kruger concludes prompt nuclear weapon radiations (particularly from fusion-capable weapons) are sufficient to destroy biological warfare stores by depositing in excess of 1 Mrad of dose in bulk-storage containers within a radius of approximately 50 meters from the detonation.

A related 2000 study by Woolson, et al. [138] relies on three-dimensional MCNP4 models informed by one-dimensional discrete ordinates methods to calculate the energy absorbed by chemical and biological munitions contained in hardened missile submunitions. From the MCNP4 calculations, the team determined that enhanced radiation weapons could achieve the necessary kill criteria (i.e., dose or heating) for the threat munitions assumed at specified standoff distances.

2.3 Graph Analysis in System-of-System Vulnerability Analysis Studies

As noted in §2.1, researchers and analysts have pursued a number of different approaches to military SOSVA. Only one of these includes the application of graph analysis to the problem. Graph analysis does, however, find acclaim in realms beyond military SOSVA. In fact, a cursory literature search reveals extensive application of graph analysis to vulnerability problems in general and to SOSVA in particular. Many of these studies perform graph analysis on physical networks such as utility distribution grids (e.g., power, water, natural gas) and telecommunication grids (e.g., internet and intranet). The following sections deliver a brief history of graph analysis and a sample of such work pertinent to this approach in the development and application of NuSCAP. While much of the literature focuses on cyber and information technology vulnerabilities, discussion of graph theory applied to SOSVA here is constrained to studies of physical vulnerability analyses.

2.3.1 The Origins of Graph Theory

Although the first textbook on graph theory was published only in 1936, graph theory began in earnest with Euler's 1736 publication of a solution to the Königsberg bridge problem [139]. In his presentation of the solution [12, 140], Euler sought to determine whether a path exists across seven bridges spanning five branches of a river to connect four bodies of land (see fig. A.4) wherein each bridge is traversed exactly once by a traveler. From his dissection of the problem, Euler developed what we now refer to as a mathematical graph. A graph, in this sense, is not a visual representation of the relationship between variables in an algebraic function. Rather, it consists of a finite set of discrete vertices (e.g., dots) joined by a finite set of edges (e.g., lines) that represent the relative position and connectivity between the vertices. Put succinctly by Trudeau [141]: "'Graphs' are networks of dots and lines; they have nothing to do with 'graphs of equations.'" Two vertices connected by an edge are said to be adjacent. A path (i.e., a course along which a traveler may move from one position to another, perhaps first traveling through an intermediary position) is defined in a graph as:

> a sequence of vertices and edges,
>
> $$v_0, e_1, v_1, e_2, v_2, \ldots, v_{r-1}, e_r, v_r,$$
>
> in which each edge e_i joins the vertices v_{i-1} and v_i $(i = 1, ..., r)$ [140, p. 9].

2.3.2 Dijkstra's Shortest Path Algorithm

In 1959, Edsger W. Dijkstra reported methods [142] by which the shortest distance between all vertices in a graph and the shortest distance between any two vertices in a graph may be calculated. The second method Dijkstra presents is now known as Dijkstra's Shortest Path Algorithm, or simply, Dijkstra's Algorithm. In this algorithm, a distance (weight) is applied to each edge of the graph. In summary, a beginning vertex is selected from which the distance to its adjacent vertices is recorded. Next, the nearest vertex is visited and the distances to its unvisited, adjacent vertices are recorded. If the second vertex shares an adjacent vertex with the beginning vertex, the distances from the beginning vertex to the co-adjacent vertex are compared; the shortest distance (lowest weight) and the nearest intermediate vertex are recorded. This pattern continues by visiting the nearest vertex to the last previously visited vertex until every vertex in the graph has been visited and all shortest path lengths recorded. Thus, the shortest path from any vertex in the graph to any other vertex in the graph may be known.

Application of Dijkstra's algorithm by the NetworkX Python package is discussed in §3.2.4.1 and §4.1.1 as it pertains to this work.

2.3.2.1 Dijkstra's Algorithm Example

As an example: consider a weighted graph (see fig. A.6) of the Königsberg bridge problem with arbitrarily assigned edge weights (distances).

Vertex `A` is chosen as the starting point (see fig. A.7); note that `A` is adjacent to three vertices `B`, `C`, and `D`. As shown in table B.1, before evaluation, it is assumed that every vertex is infinitely separated from `A` (i.e., disconnected from `A`). The results of each subsequent step are recorded in table B.2. Starting at `A`, the shortest distance to each of its adjacent vertices is recorded. Since two edges connect vertex `A` with both vertices `B` and `C`, the lesser of the two weights for each pair $(\texttt{A}, \texttt{B})$ and $(\texttt{A}, \texttt{C})$ is recorded.

Next, the nearest adjacent vertex to `A` is visited, `B` (see fig. A.8). Vertex `B` is adjacent to vertices `A` and `D`. The shortest distance between `A` and `B` was recorded in step zero, so the edge $\{\texttt{B}, \texttt{D}\}$ is the only one of concern. In this case, its weight is one. Thus, by traveling from `A` to `D` via `B` requires a distance of two. This is the same distance as moving from `A` to `D` directly by way of edge $\{\texttt{A}, \texttt{D}\}$, so no change is made to the tabulated values. Subsequently `D`, the next nearest vertex adjacent to `A`, is visited (see fig. A.9). Vertex `D` is adjacent to vertices `A`, `B`, and `C`. Its distance from `A` is recorded. Edge $\{\texttt{D}, \texttt{B}\}$ is of weight one, making the traversal from `A` to `B` via `D` a distance of two. Since this value is greater than the distance of edge $\{\texttt{A}, \texttt{B}\}$, no change is made to the tabulated values. Edge $\{\texttt{D}, \texttt{C}\}$ is of weight 5, making the traversal from `A` to `C` via `D` a distance of seven.

As seven is greater than the distance of $\{\texttt{A}, \texttt{C}\}$, no change is made to the tabulated values. Finally, the last unvisited vertex, `C`, is visited (see fig. A.10). Vertex `C` is adjacent to vertices `A` and `D`. The weight of edge $\{\texttt{C}, \texttt{A}\}$ has been recorded. Edge $\{\texttt{C}, \texttt{D}\}$ is of weight five, making the traversal from `A` to `D` via `C` a distance of eight. Since eight is greater than three, the weight of $\{\texttt{C}, \texttt{A}\}$, no change is noted. At this point, all vertices have been visited and all edges inspected. In this case, the shortest path from `A` to any other vertex is the direct path.

This procedure may be thusly repeated using each vertex in the graph as the starting vertex. At the conclusion of the algorithm, the shortest path from each vertex to every other vertex in the graph is determined.

2.3.3 Recent Vulnerability Analyses Using Graph Theory

A number of recent studies apply graph theory to address vulnerability analyses problems. Three studies pertinent to NuSCAP are discussed.

2.3.3.1 Work by Johansson and Hassel

In their 2010 work [143], Johansson and Hassel apply graph theory to develop an approach to vulnerability assessment of interdependent technological infrastructure. By linking graph models of individual infrastructure systems using dedicated dependency edges, the team is able to determine the cumulative, practical effect of applying strains to the individual systems. These strains are represented by the random removal of a certain proportion of components in one or more systems across the model. Evaluating the existence or lack of specific paths between vertices in their system graphs, Johansson and Hassel are able to ascertain which system operations remain present. If particular operations are not possible, dependency edges are removed, and nth order effects are observed. For example, [143] explains

> When a power distribution substation loses its function, all its dependency edges to the nodes in the telecommunication system are removed and the consequences of the removed dependencies are evaluated in the functional model of the telecommunication system. Since telecommunication nodes are highly dependent on an electric power supply, they will lose their function if no alternative source of power exists.

The method proposed also considers dynamic aspects of these infrastructure vulnerabilities by including estimates of the duration of unavailability because of various strains applied by the analyst. Strains are

represented only by removing vertices or edges from one or more system graphs in the work. The authors make no mention of the cause for the removal.

By applying the proposed method to a model of a Swedish railway system, the pair demonstrates the ability of their method to produce global, critical component, and geographic vulnerability analyses. The authors also remark that while their model is somewhat coarse in detail, refined models of greater fidelity are possible using this approach within practical limits. Also of note is their assertion that building detailed models is challenging when multiple stakeholders (possibly in competition) are involved in the infrastructure of choice. This often produces a reticence that precludes the analyst from gaining access to desired (or even necessary) data.

2.3.3.2 Work by Zheng, Bi, and Yang

The 2011 study [144] by Zheng, Bi, and Yang applies graph theory to the vulnerability analysis of a military SOS through the lens of an automated planning problem. Contrary to the convention of Deitz, et al. [48] (cf. §3.1.2), this research team considers not only the response of physical entities to threats as the metric of vulnerability but also the performance of munitions, the attack strategy of the attacker, and the countermeasures available to the attack. In this way, the study presented more closely reflects a survivability study rather than a vulnerability study.

Nonetheless, the authors consider the physical organization of the military system, the concept of operations under which it performs its mission, and the goal of the mission itself as metrics by which to determine the vulnerability of the modeled SOS. The analysis ultimately provides insight to whether it is possible for the SOS to complete the specified mission in a condition altered by insult from hostile weapons.

The method employed a Stanford Research Institute Problem Solver (STRIPS) planning problem with its directed, leveled, planning graph as the mechanism of modeling. The graph contains proposition and action vertices along with precondition, add-effect, and delete-effect edges. This planning graph is transformed in to a rooted tree graph that undergoes a depth-first search algorithm, seeking out valid paths to proposition nodes of the initial state. If a valid path exists, a desired state is available that offers certain capabilities to the SOS.

The researchers offer an example of missiles taking action against a BTR armored vehicle. In this way, they demonstrate the action of their algorithm on the detector, firing unit, and missiles along with their data links. Although they demonstrate what a damaged (killed) entity within the model looks like and how it affects the operation of the SOS, they do not directly adjudicate weapon effects on the target entities. Rather, they simply declare model entities as damaged.

2.3.3.3 Work by Liang and Xie

Liang and Xie's 2022 work [145] applies directed graph analysis to the functional evaluation of an electrical substation subjected to seismic activity. The researchers developed a 14-body graph model of the electrical substation's major components using the MathWorks® Simulink® platform. To this model, the team applied Monte Carlo simulations to randomly sample the functional state of each component based on seismic vulnerability curves and seismic activity of various intensities. From this treatment, each component of the substation receives a binary score for functionality. Logic gates in the Simulink model determine the availability of power transmission through the substation using the binary functionality scores of all involved components.

Metrics of performance in this study are the total power transmission capacity of the substation after the seismic activity and user (downstream) access to the power supply. These were also calculated by the Simulink model.

The authors note the presence of a paradigm in which vulnerability curves in practice are not readily available in the literature. Therefore, damage characteristics and limits are assumed for a large portion of the elements in the model. Nevertheless, the researchers make clear that the model and method remain valid where more accurate damage criteria may be introduced if or when they become available.

Chapter 3

NuSCAP Method

Duty–Honor–Country. Those three hallowed words reverently dictate what you ought to be, what you can be, what you will be.

GA Douglas MacArthur

This chapter outlines the development of the NuSCAP analytical method. The NuSCAP method's basis in ARL's SCAP and other conventional SOSVA methods are discussed along with the processes involved in model and analytical scenario development. Subsequently, the model analysis process is covered. (The principles and application of logic discussed here are performed by the NuSCAP Python application detailed in chapter 4.) Finally, required data and the sources thereof are discussed.

3.1 Basis in SCAP

While NuSCAP contributes novel capabilities to the nuclear vulnerability analysis field, its basis lies in conventional vulnerability analysis methods. As discussed in §2.1.3, ARL developed SCAP in 2009, enabling a capabilities-based SOSVA approach for conventional weapon threats to military SOS. It is from this approach that the NuSCAP method takes inspiration and seeks to improve upon by creating the ability to analyze a SOS against nuclear weapon threats.

3.1.1 Capabilites-based SOSVA

A detailed description of the SCAP method is provided in §2.1.3 and its supporting references. Like SCAP, the NuSCAP method relies on the guiding principle that: "components are grouped into sub-systems, they

will produce functions that will provide the capability to complete the mission" [10]. By examining both the physical elements of a SOS (i.e., personnel and hardware) along with the interrelationship of these, one may determine which elements and relationships produce certain critical functions and capabilities. Conversely, understanding which physical elements of a SOS lose functionality as the result of insult by (in this case) a nuclear weapon, permits one to determine how capabilities are degraded or lost in a given scenario.

It is important that NuSCAP adheres to the paradigm of degraded-states capabilities assessment. In doing so, the results provided by NuSCAP allow the operator, the commander, and the analyst to share a common understanding of any given SOS and its capabilities following insult by a nuclear detonation. As [10] points out, the historical practice of providing the measure known as loss of function (LOF) confounds the utility of a vulnerability analysis. To build upon an example in [10], a vehicle that has suffered a "50% loss of mobility" leaves the operator (for instance) unsure of whether the vehicle is limited to driving only forward (i.e., the reverse gear does not function), or if it can turn to the right but not to the left, or if it can only travel at 25 mph instead of 50 mph. The quantitative approach demonstrated in SCAP and employed by NuSCAP rectifies this ambiguity by employing discrete, binned, degraded-states metrics that result in statements such as "the vehicle can travel only on improved roads" or "the vehicle can travel at a maximum speed of 30 mph." In this way, the operator and analyst understand what the vehicle is capable of, and the commander can better plan the next phase of the operation while considering the unit operating with degraded capabilities.

3.1.2 Nuances of Lexicon

Before delving into the development and application of the NuSCAP method, it is important to establish a standard lexicon, which is applied throughout the remainder of this work. As [10] discusses, many potential lexicon conflicts exist between the test and evaluation community, the military in general, and those in the vulnerability analysis field. This section establishes definitions to construct a common understanding of language used henceforth. These terms generally follow those presented in [10], but they are discussed here for completeness. The reader will note that some of these terms take on additional meaning during discussion of the NuSCAP application and case study presented in chapter 4 and those that follow.

Element — Much discussion will be given to elements of the SOS to be analyzed. In this context, an element refers to a physical part or piece of the SOS in question. This broad definition includes components, subsystems, and systems. The size or purpose of an element is not important, but rather the importance lies in the physical manifestation of the element upon which nuclear weapon environments (i.e., blast, thermal radiation, ionizing radiation) may affect damage.

Component The term component refers to elements at the lowest level of indenture within a SOS. Components may, indeed, be individual parts (e.g., the barrel of a machine gun or the soldier operating the machine gun), or a component may be a line-replaceable unit (LRU) that consists of many parts and pieces such as the receiver/transmitter unit of a long-range radio set. In this study, the term component is limited to these definitions. That is to say, this work will discuss the vulnerability of a two-way radio's receiver/transmitter unit rather than the many circuit boards, keys, and transistors that compose the receiver/transmitter unit.

Subsystem The term subsystems refers to an aggregation of components that work together for a specific purpose. In the case of a tracked vehicle, the track subsystem is composed of individual components (i.e., track pads, end caps, and end cap bolts) which when assembled, support the weight of the vehicle and contribute to the transfer of motive forces to the ground.

System In NuSCAP, a system is defined as an individual, physical unit composed of one or more subsystems and/or components that is capable of producing one or more measurable warfighting capabilities. In this vernacular, it is perhaps most convenient to think of a system as a combat vehicle or platform (e.g., a main battle tank). In this case, the tank is composed of many subsystems (e.g., the turret and its firing subsystems, the hull and its mobility subsystems) which are, in turn, composed of many components. These copious physical elements all are assembled together to provide measurable capabilities such as firing the main gun of the tank and traveling across rough terrain. The SOS is a network of systems assembled through some means of communication—physical, logical, or otherwise—to achieve a common goal. A tank company, a unit of twelve or more main battle tanks all connected by a tactical radio network to conduct a coordinated attack, is one example of a SOS.

Functionality Elements in NuSCAP are referred to as either functional or dysfunctional. Functional elements are those that perform "as intended by the system's designers without any measurable degradation" [10]. Conversely, dysfunctional elements are those that are degraded in performance, incapable of performing at all, or are absent from the system. Dysfunctionality includes but is not limited to: degradation for want of maintenance, degradation or inoperability because of damage from hostile environments, or absence because of removal or expenditure.

Capabilities It is also useful to define what is meant by a system's capabilities. A system-level capability is the culmination of elemental functionality in aggregate; it is an observable, measurable, and

repeatable output of the system [10]. When an analyst identifies and defines the capabilities that will be measured by a NuSCAP evaluation, it is important to identify those that are pertinent to mission success. Thus, it is incumbent on the analyst to compare his approach with the scenario in which the analysis will be used, the governing doctrine, and the mission objectives for which the system or SOS is responsible. The capabilities of the SOS are an aggregate of the capabilities of its constituent systems. In the discussion that follows, it is demonstrated that system capabilities are linked at the SOS level to determine the residual capabilities of that SOS.

Vulnerability Finally, a note about vulnerability analysis in particular: vulnerability analysis falls within the scope of the larger SLVA field of study. A propensity exists among the uninitiated to refer to vulnerability studies and survivability studies synonymously. While the two are closely related, it is important to make a distinction between them. A survivability analysis determines the overall capacity of a system "to avoid, withstand, or recover from damage to a system or crew in hostile (man-made or natural) environments without suffering an abortive impairment of its ability to accomplish its designated mission" [48]. According to this definition, the survivability of a system (and that of a SOS) is a function of two subordinate characteristics: susceptibility and vulnerability. Susceptibility refers to "the characteristics of a system that make it unable to avoid being engaged by threats...being detected, tracked, targeted, and engaged, up to the point of being hit" [48]. Vulnerability, on the other hand, refers to "the characteristics of a system that cause it to suffer degradation...as a result of having been subjected to a hostile environment" [48]. The NuSCAP method should be viewed strictly in the context of vulnerability. Thus, in all NuSCAP studies, it is implicit that the SOS in question is inherently susceptible to hostile action by nuclear weapons.

3.2 SOS Model Development Process

NuSCAP is a complex analysis process. However, it starts with a patently obvious step: selecting the SOS to be analyzed. Once the SOS is identified, the work can begin in earnest. While a top-down or bottom-up approach may be taken to the SOS analysis, the top-down approach is preferred by the author and discussed here. This preference results from the author's initially deeper technical understanding of the macroscopic structure and purpose of the SOS as compared to that of the individual systems of which the SOS is composed. The opposite approach is possible and will yield equivalent results.

It is preferable that the analyst be assisted by a robust team. This team should consist of personnel who have extensive experience operating each of the constituent systems that compose the SOS, a systems engineer with experience in criticality analysis, and military tacticians or strategist who posses a working knowledge of how the SOS is intended to be employed in practice. In this work, it was not feasible to assemble such a team, so a number of more-or-less well-informed assumptions and inferences were made in the case study that follows in chapter 5. Section 6.2.3 suggests a preliminary structure for such a team.

When undertaking such a process, the team (or in this case, the individual analyst) should assemble requisite data and documentation. Many of these are discussed in the sections that follow. They include, but are not necessarily limited to: doctrinal publications related to the composition and employment of the SOS and its constituents, force development and other organizational documents that outline the structure of the SOS, T&E and maintenance data that may contain physical limits of SOS elements, and after-action review (AAR) documents from use cases in hostile environments or particularly harsh field conditions. The latter of these, even when anecdotal, may provide the analyst with insight into understanding a SOS's design, actual manner of employment (which sometimes differs from that recorded in doctrine), capabilities, and limitations.

3.2.1 Doctrine and Organization

Beginning with the SOS, the analyst disintegrates it into its constituent systems, and from there, each system into its subsystems, and each subsystem into its components. Each of these parts and pieces constitute an element of NuSCAP's SOS model. This process is perhaps most effectively accomplished by referencing force development documents, doctrine, and technical manuals in the case of a military SOS.

The analyst should begin the model development by consulting the doctrinal and organizational documents that govern the SOS to be analyzed. By examining the doctrine surrounding the chosen SOS first, the analyst will gain a working understanding of the SOS macroscopic structure and the context within which it is intended to be employed. For the US Army case, this documentation comes in the form of Army Doctrine Publications (ADP), Army Techniques Publications (ATP), Field Manuals (FM), Soldier Training Publications (STP), and Training Circulars (TC) available at `https://armypubs.army.mil/default.aspx`. Not only do these doctrine outline the SOS's mission and the essential tasks it must perform, but they also define the linkages between personnel, equipment, and those essential tasks—all of which are necessary to create a SOS model in NuSCAP. As an example, *ATP 3-20.15 – Tank Platoon* [146], defines the structure of the platoon (both personnel and equipment), its relationship to the larger tank company, its capabilities and limitations, and its role in offensive, defensive, and stability operations. Also included in doctrinal

publications are likely combat formations in which the SOS may be employed. These will provide insight into the relative physical location of individual systems in 3-D space while conducting operations—information important to accurately positioning the SOS within the computational NuSCAP model.

After gaining an understanding of the doctrine surrounding the SOS, it is necessary to further inspect the organization of the military unit to which the SOS belongs. The modified table of organization and equipment (MTOE) document outlines the required and authorized quantity of equipment (by type) and personnel (by experience and occupational specialty) that compose a military unit. An excerpt from a typical MTOE document is shown in figure A.11. The unit may be comprised of one or more SOS, or it may be a part of a larger SOS. The equipment listing portion of the MTOE will guide the analyst toward pertinent technical manuals and data that support the development of a SOS model and the analysis thereof in nuclear weapon environments. The MTOE also includes equipment readiness codes (ERC) that qualitatively expresses the importance of each piece of equipment. Those items listed as ERC P are defined by the Army as "pacing" items—or, "those major weapon systems...and other equipment items that are central to the organization's ability to accomplish or provide core functions/designated capabilities" [147, §5-4.c.]. The ERC data provide a baseline guide for performing a criticality analysis on the SOS.

While this work focuses strictly on application to a military SOS, NuSCAP may be applied to any SOS. Analogous documents should be sought out in civilian use cases. Under certain circumstances, it may also be prudent to consult special orders, plans, or training scenarios of interest. These may alter the typical use and/or organization of the SOS in a substantial manner.

3.2.2 System of Systems Sketch

During review of doctrine and organizational data, the analyst should develop a logic sketch of the SOS in the form of a basic fault tree. This act develops the basis of the mathematical SOS graph that will be used to evaluate its functionality and capabilities later in the NuSCAP process. It also provides a visual reference for understanding the general interrelations of each of the constituent systems with all the others. Furthermore, by sketching out the macroscopic fault tree depiction of the SOS, the analysts creates his first tool to support criticality analysis and focus the level of detail built into the SOS model. As the fault tree takes shape, note the existence of serial and parallel elements paying especially close attention to potential single points of failure.

The goal of this step is to graphically link all constituent systems of the SOS in a way that demonstrates required and redundant relationships between the systems. Following the style of [10], terminal vertices of

the tree (i.e., X and XX) are used to indicate the beginning and end of the tree, respectively. In principle, for a SOS to perform its basic mission(s), a viable path must exist through the fault tree connecting X with XX. An exemplar fault tree sketch constructed by application of theory described in the preceding paragraphs is shown in figure A.12. This graphic supports the following example.

In this case, the doctrine specifies that the SOS must be able to perform certain capabilities, to wit: observe its surroundings, detect and identify hostile target(s), and engage those target(s) with its weapon system(s). One notes by inspection of the systems' relationships that the execution of this SOS's mission requires electrical power provided by an electric power plant or a local, civil electrical grid. This electrical power enables the target sensor and command and control systems to inform and direct the actions of six weapon systems. By the construction and inspection of this fault tree, one may infer that only one of the six weapons systems is required to engage a target. This criterion is based on the SOS's mission and doctrine, which here is assumed to require only one target need be engaged at a time. However, when the fault tree is endowed with greater detail and evaluated as a mathematical graph, this need not be the case.

Through construction of the simple fault tree, the analyst also observes that the target sensor and command and control systems are critical systems without which the SOS cannot perform its mission—these are also single points of failure in this case. Inspection of the SOS's unit MTOE also informs the analyst that these two systems (along with each of the weapon systems) are ERC P items critical to the unit's mission. These factors together indicate that focus should be given to these systems during SOS model development and analysis using NuSCAP.

3.2.3 Individual System Studies

Following the top-down approach, the analyst should next explore each of the constituent systems found in the SOS. In the context of a military SOS, perhaps the most efficient source of information about each system is the system technical manual(s) (TM). Within Army TMs, the analyst finds much useful data to support building a robust and sufficiently detailed model of each system. The TMs provide information regarding the purpose of the system, the purpose of its subsystems and components, their physical and logical relationships, and the functions and/or capabilities provided by each element. In the TM, the analyst also finds functional block diagrams, physical characteristics, theory of operation, and troubleshooting instructions. All of these details serve to further define each system and its elements such that they can be appropriately arranged and evaluated against threats in a computational model. In addition to formal technical publications, the analyst should also explore available supplemental communications such as maintenance bulletins, modification

work orders (MWO), and safety messages that may convey liabilities, physical element limitations, or other pertinent information. Expertise from system operators and engineers should be sought out and incorporated as pertinent. The analyst should prefer data pertaining to the system in the status quo—many systems of interest undergo periodic upgrades and changes that may not be reflected in the most-recent TM.

3.2.3.1 Criticality Analysis

Through careful examination of doctrine, technical, and organizational documentation, the analyst (preferably in consultation with SOS experts) must conduct a criticality analysis to define the scope of the analysis and determine which elements of the SOS are particularly important to mission success. Technical methods behind conducting a SOS-level criticality analysis are well-established in the literature [148, 149]. It is desirable that an expert in such matters is a member of the analysis team, or that the analyst consults such literature to ensure a thorough criticality study. Furthermore, the analyst should seek input from SOS experts and operators, and weigh this advice heavily in the criticality analysis process. As a byproduct of the SOS criticality analysis, the team should note the specific physical and functional relationships that produce the mission-critical capabilities within the SOS. It is often helpful to sketch these relationships out and maintain a written record during the criticality analysis. These relationships form the core of the NuSCAP method as will be shown in the remainder of this chapter.

Should NuSCAP find eventual utility as a tool in the acquisitions phase of the the JCIDS process, the converse point is also true. A team of military experts, engineers, and human resources managers should identify the capabilities desired of the SOS and seek to build resilient elements and relationships that reduce vulnerability to nuclear weapon effects. As a matter of course, the resulting technical and organizational data will support this resilient SOS.

3.2.3.2 Dysfunction Threshold Criteria

During this phase of the model development, the analyst should take note of dysfunction thresholds for systems and their subordinate elements corresponding to nuclear weapon environments of interest. Those considered in NuSCAP are: static overpressure, dynamic overpressure, thermal radiation fluence, neutron fluence, neutron dose, photon dose, and photon dose rate. A dysfunction threshold for the purposes of NuSCAP is defined as a magnitude of exposure to a physical phenomenon beyond which an element is either known or not expected to perform as designed. This threshold may correspond in actuality to catastrophic failure, transient or permanent degradation in performance, or (on occasion) no ill effect at all. Regardless, these values establish the baseline for analysis beyond which an element cannot be relied upon to perform its

intended role in the SOS.

It is desirable that such thresholds are sourced from system specification documents, T&E data, maintenance data, or firsthand accounts of failure from exposure to extreme field environments (e.g., extreme heat, fire, lightning strike, high winds). As an example, the Equipment Data table of the operator's TM for the weapon systems explored in the case study SOS report maximum allowable wind velocities for which the weapon system is designed to operate. These maxima are recorded as dysfunction thresholds for that system in dynamic blast loading environments.

3.2.3.3 Degraded Capability States

While exploring technical and doctrinal data for each system, the analyst should also identify states of degraded capabilities for each system and the SOS as a whole. This process should involve consultation with system operators and/or designers as well as with the aforementioned documentation. The goal is to establish the possible degraded modes of operation for each system capability along with the specific damage criteria corresponding to each mode.

By way of example: consider a system that must transmit data to one or more other systems within a SOS. The preferred method of operation utilizes a digital computers, modems, and optical fiber cables to transmit, carry, and receive the data. Because of exposure to an environment of a magnitude that exceeds one or more dysfunction threshold(s) of a fiber optic cable, this method of data transmission becomes unavailable. However, the design features of both the transmitting and receiving systems contain an alternate means of data transmission to support geographically dispersed operations, to wit: FM radio receiver/transmitter subsystems. For the sake of argument, this example assumes that the FM radio subsystems of both the transmitting and receiving systems remain functional. Thus, the SOS's capability to communicate data between systems is degraded but still present. It simply exists in a limited state.

In NuSCAP, degraded capability states are represented by discrete bins. Note here that the first bin shall always represent the bin of highest capability—the "fully mission-capable" state. Likewise, the final bin shall always represent the state in which the capability is not possible in any form—the "non-mission-capable" state. Discrete bins of monotonically decremental capability compose the interstitial bin(s). With regard to the example provided the bins would be assigned thusly:

1. Communicate data via optical fiber or FM radio,
2. Communicate data via optical fiber only,
3. Communicate data via FM radio only, or

4. Not possible.

In the example presented, the second capability bin is occupied only if the opposite case given in the example were true. Note that the NuSCAP application evaluates the "not possible" bin(s) immediately after the first, highest capability bin. This is done for procedural reasons discussed further in §4.1.1.2 and §4.1.1.3.

For each discrete bin, a corresponding set of system elements and relationships must remain functional. Here, in bin 1, all elements that enable fiber optic and radio communications in both the transmitting and receiving systems remain functional. In bin 2, the FM radio receiver/transmitter subsystem in one or more systems is dysfunctional, but the fiber optic communications subsystems remain functional. In bin 3, the optical fiber equipment in one or more systems is dysfunctional, but but the FM radio communications subsystems remain functional. In the fourth bin, some critical element(s) of both data communication subsystems in one or more systems are dysfunctional, thus precluding any data transmission or receipt.

During the individual system study, the analyst should note the possible degraded states bins, the elements of the system(s) upon which those degraded states bins rely, and the relationships among those elements. In any case, the bin structure should be defined such that the number of bins is sensical and manageable—fine enough to indicate loss or retention of a militarily significant capability but not so fine as to become cumbersome or to make one bin difficult to distinguish from its neighbor. In literature [10] and in practice, three to five bins seems a commonly sufficient number. However, in some cases devoid of much systemic redundancy, a binary scenario may present itself.

3.2.4 Mathematical Graph Implementation

Graph analysis as an advancement beyond SCAP's numerical method representation of a system is essential to NuSCAP's utility as a nuclear SOSVA method. Discussions early in this work with Mr. Kevin Agan, the author of SCAP, encouraged the investigation of graph theory as a method of analysis. At the time, Agan stated he was unaware of any study in which graph theory was applied to a military SOSVA problem at large, and certainly not within the DoD [77]. Following thorough review of the literature, a single example of such a study is found in [144] (see §2.3.3.2). The study by Zheng, et al. [144] does not adjudicate any weapons effects on the nodes[1] of the graph, consider the effects of nuclear weapons, or include the ability to calculate degraded capability states in its analyses.

Here, the use of graph analysis is discussed in comparison to SCAP's use of algebraic expressions. Also, the development and implementation of system and SOS graphs are discussed.

[1]Use of the term node here, as opposed to vertex in §2.3, seeks to conform with the nomenclature used by the NetworkX Python package employed in NuSCAP. Nodes and vertices are otherwise synonymous in this work.

3.2.4.1 Graph Theory vs. Algebraic Expressions

A system model created in SCAP is analyzed using two general equations (equations (2.6) and (2.7)) whose terms are combined based on the parallel and serial structure of elements within the system of interest. While these expressions provide correct solutions based on binary inputs corresponding to element function or dysfunction, the complete equations grow in length proportional to the quantity of elements in a given system. Considering the complex combinations of serial and parallel relationships between elements that exist in most relevant systems and the branch-wise product-sum equations required to evaluate parallel branches, the complete equations quickly become unwieldy. Furthermore, simple typographical errors in grouping of terms and/or joining of equations would produce erroneous solutions with no warning to the analyst.

Conversely, in NuSCAP, the elements of a system and the relationships between those elements are represented as a DAG. By the creation of mathematical system graphs that are readily visualized and capable of demonstrating elemental functionality to the user in a graphical sense, many potential pitfalls are avoided. Graphs may be constructed manually with a writing utensil and paper, but more practically, they are constructed using one of many available graph visualization and analysis software programs. In the latter case, the construction of a graph only requires the user to present the computer interface with ordered pairs of adjacent nodes, lists of adjacent nodes, or the names of adjacent nodes connected by a specific character string (e.g., '`--`', '`->`'). Visualization methods specific to the particular software package chosen allow the user to verify the accuracy of the graph against notes, sketches, and functional block diagrams pertaining to the system in question. Additionally, the user may define color, shape, and texture indicators for various conditions such as dysfunctional nodes, administrative nodes, etc. These simple features permit troubleshooting and error identification that do not require painstaking proofreading of lengthy n-term algebraic expressions.

Most importantly, the traversal of a graph of this nature with properties of each system element endowed to its nodes and edges is mathematically equivalent to Agan's algebraic expressions. Subsequent sections address these properties in greater detail, but chief among them is the functionality of the element held within the node. Dysfunctional nodes in NuSCAP graphs are equivalent to system elements with a binary score of zero in SCAP. In NuSCAP, all edges incident to such a node are removed and along with them, its adjacency with any other node in the graph. If a certain set of edges is removed, a path connecting the terminal nodes no longer exists, and the tree is calculated to be dysfunctional. A number of basic example graphs and their corresponding numerical equations are provided in appendix C as demonstration of this concept.

3.2.4.2 The System Graph

A DAG appears similar to a fault tree—and is so with the notable exception of the richer data present in mathematical graph nodes and edges. In NuSCAP, graphs are composed of nodes falling into three categories: terminal nodes, administrative nodes, and elemental nodes. Terminal nodes and administrative nodes are assigned no characteristics with the exception of a name for identification purposes. The beginning terminal node serves as the root of the tree (named node `X`) from which traversal of the graph begins to determine continuity with the downstream terminal node (named node `XX`). It is from this continuity that system functionality is calculated. Administrative nodes function as visual cues and logical checkpoints between which the graph is traversed to calculate the presence or absence of a capability within the specified bin structure. These nodes are derived directly from the analyst's understanding and assessment of the system structure (both physical and logical) as discussed in §3.2.3. Elemental nodes represent the physical elements of the system and are endowed (instantiated, see §4.1.1.1) with many qualities of the object they represent. Elemental nodes should be thought of as objects with names, types (equipment or human), physical locations and orientations, dysfunction thresholds, and functionality statuses. The directed edges within all NuSCAP graphs are unweighted, a condition that causes the computational methods discussed in §4.1.1.2.2 to assign all edges an equal weight of unity. It is of note that edge weight is unimportant in NuSCAP. Edges within a system graph need not connect nodes in sequential order (i.e., the order by which a physical or logical process occurs in a temporal sense), but rather, they connect nodes in series or parallel arrangement that is required to provide functionality and capability.

A representative system graph for an electric power plant (also known as System 3 in the case study SOS) is shown in figure A.13. Terminal nodes are represented by rounded boxes labeled `X 3` and `XX 3` according to the convention of this work. The administrative nodes are depicted as lozenges with labels including a double-alphabetic character designation followed by the system number (e.g., `AA 3` and `BB 3`). There is no reason for this generic naming convention beside convenience. The analyst may name administrative nodes according to need or desire, taking note to be consistent throughout the SOS model. Consistency is important as it establishes a common label for assessing the presence of SOS-level capabilities linked across systems. The procedure for this follows in §3.2.4.3.

3.2.4.3 The SOS Graph

The SOS graph differs little from its constituent system graphs. Simply put, the SOS graph expands on the SOS fault tree sketched in §3.2.2 to include more detailed descriptions of the systems and capability

links. The SOS graph is composed of each system-level graph for the systems that compose the SOS. By composing the SOS of independent system graphs rather than constructing it by assembly of otherwise dissociated elements, a NuSCAP analysis is able to report dysfunction and capability data at the system level and the SOS level simultaneously. In the SOS case, administrative nodes and terminal nodes take on a hierarchical naming convention. Those belonging solely to the SOS adhere to the established norms of `X` and `XX` for terminal nodes and `AA`, `BB`, etc. for administrative nodes. Those belonging to an individual, subordinate system are given alphanumeric designators: `X 1` and `XX 1` as terminal nodes and `AA 1`, `BB 1`, etc. as administrative nodes belonging to System 1. The individual system graphs are then linked by edges indicating the existence of corresponding capabilities in two or more linked systems. In NuSCAP, these edges do not necessarily connect systems at, immediately above, or immediately below the elements that enable a particular capability. Rather, the edges are placed such that they create a path which, when traversed, quantifies the existence or absence of the capability.

Figure A.14 shows a portion of an SOS graph depicting elements of an electric power plant system and a command and control system. By traversing the SOS graph from `X 3` through `DD 3` to `DD 1`, the analyst determines that the electric power plant is capable of generating electricity and powering the command and control system by supplying power through `Cable J4`. The capability (orange) edge coincident with `DD 3` and `X 1` enables this determination.

The bookkeeping of numerical system designations is the province of the analyst, but it is often aided by the doctrine and organizational documents discussed in §3.2.1. In the convention used for the NuSCAP case study in chapter 5, numbering adheres to the system used in Army TMs for the SOS assigned to this study. The numbering system follows.

1. Command and Control System
2. Target Sensor System
3. Electric Power Plant System
4. *Not used*
5. Weapon Systems (Note: The SOS is composed of six weapon systems. They are thus designated 5.1, 5.2,. . ., 5.6.)

A completed SOS graph is shown in figure F.1. This graph is large and complex. It is most useful when reviewed for accuracy and completeness by display as a vector image that retains high resolution at extreme

enlargement values. Producing a visual graph is useful for model validation, but it is not entirely necessary for automated execution of a NuSCAP analysis via the NuSCAP application as discussed in §4.2.

3.3 Analytical Scenario Development

It is necessary that the analyst defines the threat scenario completely to produce useful and relevant analyses. Thus, NuSCAP requires the analyst to declare a number of details that construct the analytical scenario. These details are enumerated in this section and codified in the form of a JSON file for use in the NuSCAP application discussed further in §4.1.2.4.

It is useful to distinguish each analytical scenario by name, prepare a designated area for computational data storage (e.g., a dedicated working directory), and provide a short commentary including relevant details of the scenario for organizational and historic purposes. Additionally, the analyst must provide threat weapon characteristics and relevant geospatial data to support nuclear weapon environment calculations.

3.3.1 Operational Relevance

The guiding principles of scenario development are those that deliver operational relevance. The relevance of the analyses discussed in chapter 5 is solely that of proof of concept. In future use, NuSCAP analyses are intended as tools to support vulnerability analyses of US forces on potential nuclear battlefields. These may be used as devices for training and education of military planners and operational commanders. Otherwise, they may find utility as metrics by which operational plans are constructed and optimized in preparation for future real-world operations. It is also possible that planners may exploit NuSCAP analyses of adversary SOS to supplement strike planning procedures in order to hold adversary targets at risk in support of integrated deterrence. Regardless, the analyst should consult with those who will employ NuSCAP results to determine the most effective way to construct the analytical scenario.

3.3.2 Threat Weapon Characteristics

Relevant details regarding the nuclear detonation are required to define nuclear weapon environment calculation parameters. The analyst must specify the following data.

Yield	the total explosive energy released by the weapon [kt]
HOB	the distance above the surface of the Earth (land or water) at which the detonation occurs measured along a radial vector [m]

HOB sigma — one standard deviation with regard to the expected HOB as achieved on average by a specific weapon delivery system [m]

Circular error probable (CEP) — statistically, the radius of a circular area in which half of the ordnance delivered by a particular method will land [m]

Neutron leakage spectrum — the energies of neutrons expected to leak from the nuclear weapon detonation and the likelihood of a neutron being emitted at a particular energy

Neutron yield — the number of neutrons produced by the nuclear detonation per kiloton explosive yield [kt^{-1}]

Photon leakage spectrum — the energies of photons expected to leak from the nuclear weapon detonation and the likelihood of a photon being emitted at a particular energy

Photon yield — the number of photons produced by the nuclear detonation per kiloton explosive yield [kt^{-1}]

The analyst may optionally specify the following data.

Weapon type — the type of weapon simulated in the study; suggested options are fission, boosted fission, or thermonuclear

Fission fraction — for boosted fission or thermonuclear weapons, the fraction of total yield produced by nuclear fission processes

3.3.3 Geospatial and Atmospheric Data

The analyst must also provide certain types of geospatial and atmospheric information to permit nuclear weapon environment calculations and the appropriate arrangement of systems within the phase space of the various models used for those calculations. For required data that specify a geographic location on the surface of the Earth, NuSCAP requires coordinate inputs in the MGRS format [45, chapter 3]. This location format is commonplace in the military community for which NuSCAP is intended and supports maintaining a common vernacular. With minor changes to the NuSCAP application, standard latitude and longitude coordinates may be substituted. The analyst must provide the following data.

GIS reference datum — defines the reference geodetic ellipsoid data from which MGRS eastings and northings are referenced; WGS84 is used in this work

Ground zero location — the MGRS coordinates for the point that lies on the surface of the Earth along a radial vector passing through the point at which the nuclear weapon detonation occurs

Ground zero elevation — the vertical displacement relative to mean sea level (MSL) at which the ground zero point lies [m]

Atmospheric visibility — a measure of the atmospheric attenuation of light transmission; the horizontal distance [km] at which a dark object on the horizon contrasts enough with the surrounding sky to be discernible in daylight [150]

System location — the surface MGRS coordinates for the geometric center of the bottom surface of each system included in the analysis

System elevation — the elevation relative to MSL at the surface location for each system included in the analysis [m]

System R95 — the radius of a circle which circumscribes 95% of the system's constituent components [151] [km]; used only for widely dispersed "area" targets and is zero for point targets

System depth — the depth below the surface at which the system exists if buried [m]

System heading — the orientation of the front of the system with regard to true north [degrees]; clockwise is positive

The analyst may optionally provide the following data.

date-time group (DTG) — the date, time, and local NATO time zone designator of the nuclear detonation in standard DD HHMMZ MON YYYY format [16, p. 2-2]; e.g., 06 0815I AUG 1945 (the bombing of Hiroshima)

3.3.4 Other Input Variable Requirements

A number of other inputs are required to support computational needs for the NuSCAP application. While these may not be necessary to apply the NuSCAP method, they are required for automation of the process. Some of the data discussed here are unique to the tools and computer codes chosen for this work. If other applications are substituted for one or more of these, the data requirements may change. These topics are mentioned here for completeness, but a more directly applied discussion is given in §4.1.2.

Working directory path	the absolute path to the directory on the computer system where the analysis will be performed
MCNP code path	the absolute path to the MCNP executable on the computer system
MCNP data path	the absolute path to the MCNP data directory on the computer system
MCNP threads	the number of parallel processors the analyst desires to use for calculations performed with the MCNP code
NPS	the number particle histories the analyst desires to run using the MCNP code; this quantity is used in separate neutron and photon MCNP6.2 calculations
SNEC path	the absolute path to the directory where the SNEC web multiple effects module is stored on the computer system
Response functions	coefficients of multiplication for MCNP6.2 tally results to produce quantities of interest (i.e., dose to personnel, dose to equipment, and 1 MeV neutron equivalent fluence); discussed more in §3.4.1.3
Transport materials	composition (by chemical element and/or isotope) and mass density [g·cm^{-3}] of materials to be included in the radiation transport calculations during the analysis; provided in ZAID format [152, §5.6] along with weight fraction or atom fraction abundances

3.4 SOS Model Analysis

The analysis of a SOS within the NuSCAP method includes the evaluation of all SOS elements against the nuclear weapon environments to which they are exposed. The subsections here discuss the methods by which the nuclear weapon environments are calculated, how elemental evaluation is performed, and how the functionality and residual capabilities of the SOS and its systems are quantified.

3.4.1 Nuclear Weapon Environment Calculations

The fission (and in some cases, fusion) of a vast quantity of atomic nuclei during a nuclear weapon detonation releases an immense amount of energy into the surrounding environment in a short time. From this powerful explosion, extreme environments of temperatures, pressures, and energetic radiations are created

from which a wide variety of effects are generated. Many of these environments are potentially damaging or destructive to personnel and equipment. The physical processes behind the manifestation and propagation of these effects are given rigorous treatment in works by Bridgman [153], Brode [154], Glasstone and Dolan [19], and Northrop [155] among others.

The NuSCAP method is intended to analyze a SOS in the atmosphere on or near the surface of the Earth which has been exposed to the prompt effects of a nuclear weapon detonation. Thus, at this point, NuSCAP is not an appropriate tool to analyze a SOS located underground, undersea, or outside the Earth's atmosphere. Likewise, at present, NuSCAP does not account for late-time nuclear weapon effects such as those which may emanate from radioactive fallout or neutron activation of materials found in the environment or SOS elements. In this first development and demonstration of such a method, a number of assumptions are made to this effect:

1. the SOS and its elements are located within the Earth's atmosphere;
2. the SOS and its elements are located near the Earth's surface; and,
3. the area in which the SOS is located is reasonably flat, unforested, and rural.

The magnitudes of the eight nuclear weapon environments considered by NuSCAP are calculated using three software programs: the USSTRATCOM PDCALC program, the LANL SNEC program, and the MCNP code. The calculational methods employed by each code are discussed here relative to the quantities each provides within the NuSCAP method. It is of note that many other fast-running or high-fidelity nuclear weapon environment calculators exist and could be substituted at the desire of an analyst or customer [36, chapter 7].

Should one so choose, an analyst may also consider the effects of EMP on the elements of a SOS. A wide variety of computer codes including DTRA's ElectroMagnetic Reliability and Effects Prediction (EMREP) tool, the High-Altitude Electromagnetic Pulse Target Analysis and Planning System (HEMPTAPS) [36, chapter 7], and the Source Region Electromagnetic Pulse Target Analysis and Planning System (SREMPTAPS) [36, chapter 7] may be used to calculate the magnitude of EMP fields in such a case. The generation and effects of EMP are not further discussed in this work.

A requisite step prior to beginning any nuclear weapon environment calculations is the location of all elements in the SOS being modeled relative to the AGZ location. Specifically, the range to AGZ and slant range are important values to calculate for each element. Cartesian coordinates and rudimentary trigonometry are all that is required to do so, but a reasonably detailed SOS model is likely to contain hundreds of elements.

This may warrant automation of the process. Such automation is included in the NuSCAP application discussed in §4.1.1.

3.4.1.1 Blast

Blast environments are measured most commonly by two metrics: static overpressure and dynamic pressure, both of which are expressed in units of pounds per square inch (psi) in NuSCAP. Static overpressure refers to the magnitude of excess pressure caused by the blast wave in excess of the ambient atmospheric pressure that existed prior to the detonation. It is convenient to think of this phenomenon as a crushing pressure similar to that one might inflict by squeezing on an empty soda can. Dynamic pressure is that which is exerted on objects by the rapid movement of fluid mass (wind) when the blast wave interacts with an object. This is conveniently perceived as the force of the wind on the same empty soda can causing it to topple over and off of a picnic table.

The dynamic pressure is

$$q = {}^1\!/_2 \rho u^2, \tag{3.1}$$

where ρ is the air density behind the shock front and u is the windspeed behind the shock front [19, §3.55]. This relationship is important because dysfunction criteria may be expressed more commonly as a measure of windspeed rather than dynamic pressure that varies for a given scenario at different elevations or altitudes. An example is shown in figure A.15 from the US Army's technical bulletin (TB) 43-PS-747, *PS, The Preventative Maintenance Monthly* [13]. In this case, operators are warned that winds in excess of 43 mph may snap the masts on an antenna mast group system.

In NuSCAP, blast environments are calculated by two computer programs. The PDCALC code calculates the magnitude of peak static overpressure and peak dynamic pressure. The LANL SNEC tool calculates the peak windspeed. Additionally, the PDCALC program calculates the probability of damage (PD) because of blast environments for systems or elements (namely personnel) for which a valid VNTK exists. The VNTK code expresses a target's vulnerability to damage by blast as a function of its susceptibility to either static or dynamic pressure as scaled relative to side loading from a 20 kt surface detonation.

3.4.1.1.1 Peak Overpressure and Peak Dynamic Pressure Calculations PDCALC calculates the peak overpressure and peak dynamic pressure from a specified blast scenario using analytical approximations known as the Brode Airblast Model [44]. This model approximates pressure magnitudes and other quantities of interest as pertaining to a nuclear weapon detonation over an ideal surface. This surface type is described

as rigid, smooth, and ideally reflective [156]. Additionally, an ideal surface is assumed to have no interaction with the nuclear fireball, no surface roughness, no boundary layer, and is subject to no precursor effects [156]. The Brode Airblast Model formulae, algorithms, and analytical approximations are functions of HOB, distance from AGZ, and time and are valid for a wide range of pressures. The specific equations and methods are controlled by the US Government, and thus, are not explicitly shared here. Requests for the seminal document [156] may be made through DTIC at https://www.dtic.mil.

3.4.1.1.2 Probability of Damage Calculations The PDCALC subroutines parse the user-provide VNTK and calculate an adjusted vulnerability number (AVN) based on the T and K factors specified according to the methods of [157]. The VNTK codes include the hardness of the target relative to a specified damage level in the form of an arbitrary two-digit vulnerability number followed by a letter (T factor) indicating its predominant sensitivity to either static or dynamic pressure effects and a scaling (K factor) that adjusts the vulnerability number as a function of yield as compared to the 20 kt reference value [21]. Typically, VNTKs specify either moderate damage or severe damage criteria. Moderately damaged targets require major repair or reconstruction before the design features may be reestablished [21]. Severely damaged targets require complete reconstruction or replacement [21].

The PDCALC subroutines consider HOB, yield, distance from the target to AGZ, and CEP to determine the AVN and from it calculate the probability the specified level of damage is achieved. The formulae and methods involved in these calculations are controlled by the US Government, and thus, are not explicitly shared here. Requests for the PDCALC software and technical manual [44] may be made through USSTRATCOM at https://www.stratcom.mil/Contact/.

3.4.1.1.3 Windspeed Calculations The SNEC tool calculates windspeed via a subroutine that calls on the Nuclear Effects Models for Estimating Sensitivities to Input Scenarios (NEMESIS) code developed by the Defense Nuclear Agency [158]. NEMESIS also relies heavily on the approximations put forth by Brode [156] "with minor corrections" [150]. The windspeed is calculated from the NEMESIS derived value for peak dynamic pressure using the relationship given in equation (3.1).

3.4.1.2 Thermal Radiation Fluence

Similar to windspeed calculations, SNEC calls on an extended version of subroutines within the NEMESIS code to calculate thermal radiation fluence (i.e., radiant exposure) [158]. The SNEC thermal module expands the range of atmospheric visibility conditions accepted for consideration and also includes data from the

RECIPE and RADFLO codes to account for both unusually high and unusually low yields [158]. While the specific formulae and values used by NEMESIS and SNEC are controlled by the US Government, the general form of the guiding equation is reflected in Glasstone and Dolan's discussion on radiant exposure-distance relationships. In [19, §7.96], thermal radiation fluence in $\text{cal} \cdot \text{cm}^{-2}$ is

$$Q = \frac{fW\tau}{4\pi D^2} \times 10^{12}, \tag{3.2}$$

where f is the thermal fraction (i.e., the fraction of total weapon yield transmitted as thermal energy, also known as the thermal partition), W is the total weapon yield expressed in kt, τ is transmittance (i.e., the fraction of radiation (direct and scattered) that is transmitted through the atmosphere—a function of visibility, absorption, and distance), and D is the slant range (i.e., direct, line-of-sight distance) between the exposed object and the point of detonation in cm. The coefficient, 10^{12} represents the conversion from units of kilotons TNT to calories. The SNEC calculations are more rigorous than are [19] in treatment of the thermal fraction and atmospheric transmittance [158].

An important note considering thermal radiation fluence: because of the proportional relationship between yield and thermal pulse duration, larger yield weapons are required to deposit more thermal fluence than are low yield weapons to achieve equivalent effects. As discussed in [19, §7.30, tables 7.35 and 7.40], the dysfunction threshold for an element should be adjusted by the analyst to account for these dependencies.

3.4.1.3 Ionizing Radiation

Ionizing radiation environments included in NuSCAP consider neutrons and gamma ray photons emitted by a nuclear weapon, represented as an isotropic point source. Calculation of the magnitudes of these environments and the derived quantities thereof (i.e., dose, dose rate, and equivalent fluence) are performed using MCNP6.2. The MCNP code represents one of a few radiation transport methods (others include point kernel and discrete ordinates) and, as noted in §3.4.1, only one radiation transport code of many available to an analyst. The MCNP code is included in NuSCAP calculations because of its wide acceptance as a reliable and flexible general purpose radiation transport code as described in §2.2.

3.4.1.3.1 The Monte Carlo Method and the MCNP Code The MCNP code, as its name implies, relies on the Monte Carlo method to simulate individual particle interactions with the media through which it travels. The MCNP code models the random walk process for each particle history by randomly sampling the distribution of possible particle types in a given source, the possible energies for that particle, and the

nuclear data for the transport medium (material) in which the particle exists. From these distributions and the particle's initial state (position, energy, and direction), the MCNP code calculates the probability of an interaction, the type of interaction, and the most likely result of that interaction. This process repeats itself from the particle's initial emanation until its proverbial "death" (and that of any progeny) by absorption or scatter beyond the extents of the problem's phase space—this process constitutes one particle history. When a statistically significant number of particle histories are recorded, the Central Limit Theorem is applicable to infer the average behavior of the simulated particles in the problem.

3.4.1.3.2 Tallies and Response Functions The MCNP code permits a user to record a wide variety of data regarding particle histories in any given calculation. The mechanism by which these data are recorded is referred to as a tally. Listed below with their respective units are the seven standard tallies available in the MCNP code [152, table 2.2].

F1 surface current (particles)

F2 surface fluence (particles $\cdot$ cm^{-2})

F4 cell fluence (particles $\cdot$ cm^{-2})

F5 detector fluence (particles $\cdot$ cm^{-2})

F6 energy deposition (MeV $\cdot$ g^{-1})

F7 fission energy deposition (MeV $\cdot$ g^{-1})

F8 pulse-height tally (pulses)

For the case study presented in chapter 5, neither 3-D CAD models of the systems and elements involved nor material definitions were available. This eliminated the utility of complex CSG or UM geometries with cell fluence or surface fluence tallies. Instead, point detector fluence (F5) tallies represent each SOS element. These tallies calculate the "free air" (i.e., unshielded) fluence at each point. Thus, these tally values represent conservative figures as compared to those expected in a shielded, operational configuration. Appropriate response functions are then applied to calculate desired quantities from the tally data.

The NuSCAP method relies on MCNP6.2 to estimate neutron dose to personnel (rad), 1 MeV neutron equivalent fluence in equipment (1 MeV neutrons$\cdot$cm^{-2}), photon (gamma ray) dose to personnel (rad), and photon dose to equipment (rad(Si)) from the weapon leakage spectra specified by the analyst. To calculate these values, NuSCAP employs three neutron response functions and two photon response functions. The

ANSI/ANS-6.1.1-1977 flux-to-dose conversion factors [152, listing F.1] are used to convert the F5 point tally data into neutron dose to humans. Neutron fluence is converted to 1 MeV equivalent fluence according to the 89-group energy-based tally multiplication (`E` and `EM` card) structure provided in [159, appendix B, p. 30–31]. Neutron dose to equipment is calculated using a tally multiplier (`FM`) card filled with output data from the MatMCNP code [160] (available at `https://github.com/sandialabs/MatMCNP`), producing final values in units of rad(Si) [161]. The ANSI/ANS-6.1.1-1977 flux-to-dose conversion factors [152, listing F.20] are also used to convert photon fluence into photon dose to humans. Dose to equipment from photons is also calculated using a tally multiplier card generated by MatMCNP. While the aforementioned represent the standard response functions used in NuSCAP, other response functions may be employed at the discretion of the analyst. While these tally modification methods are used in the proof-of-concept case studies presented in chapter 5, other such conversion factors (e.g., ICRP 116) may be used at the analyst's discretion.

To simplify the calculation schema and preclude any difficulties found in multiphysics calculations, NuSCAP performs two separate MCNP6.2 calculations for each scenario: one for photons, the other for neutrons. Identical geometry, source location, tally locations, and material definitions are used in both calculations. The only notable differences in the two calculations are the source terms (particle type, energy distribution, and energy probability) and tally response function definitions. Time bins are defined from which the peak photon dose rate in equipment ($\mathrm{rad(Si)} \cdot \mathrm{s}^{-1}$) is calculated for the photon calculation. The time tally begins at zero shakes. The first bin begins one shake less than the travel time for an uncollided photon from the detonation point to the nearest element. The final time bin ends at the travel time for an uncollided thermal ($E_n \cong 0.0253$ eV) neutron from the detonation point to the most distant element in the model.

3.4.1.3.3 Model Requirements in the MCNP Code Modeling the SOS in MCNP6.2 requires the analyst to create an environment through which the emitted neutrons and photons are transported. At present, NuSCAP employs a rudimentary environment model consisting of two adjacent right, rectangular parallelepipeds (RPP) representing an earthen surface and the atmosphere. Materials definitions for the earth [162, table 116] and air [162, table 4] are taken from Detwiler, et al. Equipment elements for which the analyst desires to measure neutron dose and photon dose rate are assigned the properties of elemental silicon [161] to permit calculations in the units of rad(Si). Cartesian coordinates are employed in NuSCAP's MCNP calculations. The position of the nuclear detonation serves as the origin of the model space as a matter of convenience.

The physical extents of the model are defined based on the location of model elements. From the locations

of all elements, the maxima and minima displacements of relative to the AGZ in the x, y, and z directions are determined. To these extents, a five-mean-free-path buffer is added (with respect to material in both air and earth) in all directions to provide an ample particle scatter buffer volume. The same buffer is extended vertically above the detonation point.

In the interest of maintaining accurate account of tallies, tally comment cards refer to the element name represented by each respective F5 tally. In MCNP6.2, the number of point detector (F5) tallies is limited to 1,000. An analyst who chooses to employ MCNP6.3 in future NuSCAP analyses has the option to employ up to 10,000 point detector tallies in a single input file, thus allowing capacity for a larger SOS model [80, table 6].

3.4.2 SOS Analysis

Following the completion of nuclear weapon environment calculations, the SOS is analyzed both for basic functionality and residual capability. The SOS is analyzed both as a single, cohesive unit and as individual systems to provide analysts with further insight into individual system performance.

3.4.2.1 Elemental Evaluation

The SOS analysis begins with the evaluation of individual elements against all nuclear weapon environments to which they are exposed in the scenario. The user-specified dysfunction threshold value for each environment is compared with the calculated magnitude for that environment by simple mathematical inequality. If the magnitude of one or more environments meets or exceeds the specified dysfunction threshold value for that environment, the element is dysfunctional. Upon identifying a dysfunctional element, all incident edges are removed from its node in the SOS graph. This evaluation is repeated for all elements in the SOS.

While it is sufficient that only one environment be exceeded to cause a dysfunctional element, it is prudent to assess all environments. In this way, an analyst may gain a deeper understanding of SOS and system dependencies and to which nuclear weapon environments the SOS or system is most vulnerable with regard to a particular weapon scenario.

3.4.2.2 Functionality Analysis

After all elements of the SOS are evaluated against the nuclear weapon environments to determine their functionality, the individual system graphs and the SOS graph are evaluated for overall functionality. In NuSCAP, the SOS (and an individual system) is considered to retain functionality if any path remains

between its graph's terminal nodes. Traversal of the SOS graph from `X` to `XX` yielding a positive result quantifies the existence of functionality in the SOS. Likewise traversal of an individual system graph from, e.g., `X 1` to `XX 1` quantifies the existence of functionality in System 1. Functionality, in this case refers to the existence of any remaining ability to perform task(s) as an integrated unit. The significance of basic functionality is elucidated further by capabilities analysis of a functional-but-degraded system.

3.4.2.3 Capability Analysis

Following functional analysis of the SOS and its constituent systems, SOS and system capabilities are evaluated. Recall from §3.2.3.3, that specific paths through the graph(s) within the SOS graph define the existence or absence of particular capabilities in discrete, degraded-states performance bins. Having removed all incident edges from all dysfunctional element nodes in the SOS graph affects the availability of these paths. At this point, each SOS capability is assessed starting at the most capable performance bin and working toward the bin where the capability is impossible. Each defined path or set of paths that define a bin is traversed, and the result of that traversal attempt is compared with the Boolean condition(s) specified for the capability bin. This process is repeated until a set of conditions is satisfied for a performance bin. Then, the analysis moves onto the next SOS capability to be assessed.

The entirety of this process is then repeated at the individual system level. By assessing both individual capabilities and aggregate SOS capabilities, the analyst will gain further insight into the nth order effects of that system's exposure to the nuclear weapon environments present in a scenario. This will allow commanders to more fully appreciate their systemic vulnerabilities to nuclear weapon effects and could very well serve as a mechanism by which requests for increased hardness or redundancies are formed in the JCIDS process.

For purposes of illustration: consider again figure A.13, which is the system graph of an electric power plant. One capability of this system is generating electrical power and supplying it to the target sensor system (System 2). This can be accomplished by either of the two generator sets that compose the upper half of the electric power plant's system graph. So, if a path is traversable from `AA 3` to `BB 3`, the analyst determines the system is capable of generating electrical power. In order to pass the electrical power to the target sensor system, the electric power plant must also transmit the power through the power distribution unit and a set of three transmission cables (i.e., `Cable J1`, `Cable J2`, and `Cable J3`). So, to determine whether the capability of supplying electrical power to the target sensor system exists, the graph must be traversed from `X 3` to `CC 3`. This can be accomplished by passing through administrative node `BB 3.1`, `BB 3.2`, or both. However, all the cables must remain functional, or the capability is lost. The capability bin structure for this example is given in table B.3. The same process holds true for assessing system capabilities and SOS capabilities.

3.4.3 NuSCAP Output Reporting

At the conclusion of elemental, functional, and capability analyses, it is useful to compose a report of findings related to the specified scenario. Reports at the system and SOS levels declare the overall functionality, the maximum residual capability for each capability assessed, and (in system-level reports) the functionality of each element in the system along with its cause(s) of dysfunction. That is, the report should inform the reader what elements of the SOS are dysfunctional and what dysfunction thresholds were exceeded for those elements.

3.5 Required Data and Data Sources

To sufficiently develop an analytical scenario and the SOS model for NuSCAP analyses, a requisite data set must be compiled.

As established in §3.2.1, the data supporting construction of the system graphs and the SOS graph are ascertained from doctrine, organizational documents, and technical manuals. Specific to US Army systems, doctrine publications and a limited selection of technical manuals are available via the US Army publications website (`https://armypubs.army.mil/default.aspx`). Organizational documents may be requested from the US Army Force Management System (`https://fmsweb.army.mil/unprotected/splash`). Technical manuals are available via the US Army Logistics Support Activity website (`https://ent.ldac.army.mil/etmapp`).

Also required for the system and SOS models are dysfunction thresholds as a function of element type and nuclear weapon environment. This presents a significant challenge to performing accurate elemental analyses, and thus, presents a challenge to accurate system and SOS analyses. At this juncture, there is no centralized repository of damage thresholds for components or subsystems that an analyst may use to construct military system models. Therefore, the values used for the case study in this work are anecdotal and based on best engineering judgment as determined by the author with concurrence from select members of his committee. This unfortunate paradigm is congruent with practices in conventional SOSVA studies for which quantitative threshold data is unavailable [77]. Anecdotal, assumed values are recorded and noted as such with the intent that they may be replaced at a later time by proven data. Accordingly, these values are without quantified uncertainty. Even the two dysfunction threshold values found in military literature and applied to elements within the cases studies presented as part of this work were found to be entirely lacking uncertainty values.

Little data is required to support the geospatial requirements of NuSCAP. The use of open-source mapping interfaces that support MGRS coordinate use, such as Google Earth [14], allow the analyst to lay out the systems and elements on a map or satellite image to check orientation against doctrine and obtain surface

elevation data for those locations. Atmospheric visibility data is available for most US locations via the National Weather Service website (https://www.weather.gov). For models that include a wide variety of altitudes, atmospheric density values are available from the NRLMSIS 2.0 [163] model interactive web tool (https://kauai.ccmc.gsfc.nasa.gov/instantrun/nrlmsis).

Radiation transport calculations in MCNP6.2 require source-term definitions for both neutrons and photons, material definitions for all materials included in the model space, and conversion factors with which dose values and other quantities of interest may be calculated. The sources from which these data may be drawn is vast, so a comprehensive listing is not provided here. Unclassified, unlimited distribution source terms representative of nuclear weapon neutron and photon leakage emissions are given in [68–72, 164]. Material composition and density data are available in [162] for commonly encountered substances. Another noteworthy challenge discovered during the course of NuSCAP development is that many materials of interest to military systems are proprietary in nature and are held at the discretion of DoD contractors. It is the experience of the author that these are nigh unto impossible to acquire without contractual intervention. Moreover, should studies of this be of interest to the DoD in the future, systems matriculating through JCIDS should specify reporting of chemical composition and mass density of major components in the requirement documents. Biological flux-to-dose conversion factors are available for both photons and neutrons in [65, 152, app. F.1]. Tissue KERMA conversion factors are widely reported in the literature including within some nuclear weapon source term documents [68, 155, 164]. Tally multiplication factors for dose to silicon-based hardware components may be calculated using MatMCNP [160, 161]. Silicon displacement damage conversion factors to 1 MeV neutron equivalence are available in [65, 159, table 8.2].

Chapter 4

NuSCAP Application

Peace is our profession...

United States Strategic Command motto

The NuSCAP application consists of five Python packages[1] (supported by the PDCALC code, the SNEC code, and the MCNP code) that automate the methods described in chapter 3. This chapter discusses the overall structure of the application, the function and purpose of each of the packages, NuSCAP packages' interactions with external programs, required user inputs, and guidance on executing a NuSCAP analysis from the command line. Examples of input file structures and NuSCAP reports are provided.

During development of the NuSCAP application and its packages, extensive unit testing was implemented to ensure the application performs as intended. The NuSCAP application is 98% covered (line-by-line) by

[1]The terminology used throughout this chapter becomes repetitive and convoluted at times. For this reason, the following conventions are provided to guide the reader in parsing the material herein.

The term element and variations thereon appear ad nauseam in this chapter. The word takes on several meanings with only subtle distinction between any two of these. First, element (as it appears here in plain text) refers to the physical entity discussed in §3.1.2, that is part and parcel to a larger conglomeration of objects intended to perform a function (i.e., a component, subsystem, or system). When appearing as `element`, the word refers to one of three things: the `element.py` computer file, a package of the NuSCAP computer application; a computational object instantiated to represent a physical element in computational space (i.e., a member of the `Element` class held within the `element` package); or, the attributes (properties and methods) belonging to an `element` computational object. Examples of such are the `element.name` property and the `element._set_thresholds(...)` method. Finally, `Element` refers to the class of computational object defined in the `element.py` package and to which `element` objects belong.

The terms system and SOS appear similarly throughout the course of this chapter. The preceding convention applies to these terms, too. A system, as defined in §3.1.2, is the physical assembly of many components and subsystems for a common purpose (e.g., a vehicle). The `system.py` computer file is a NuSCAP application package. A `system` object is the computational analogue instantiation of the physical system that is endowed with its own particular set of attributes. Examples of these are `system.location` and `system._calculate_ranges(...)`. The term `System` refers to the class of computational object defined in the `system.py` package to which a `system` object belongs.

Likewise, a SOS is a physical set of systems that are interconnected for symbiotic operation (e.g., a tank platoon). The `sos.py` package defines the `SOS` class of objects to which `sos` objects with their own particular set of attributes (e.g., `sos.functionality` and `sos.save_sos_graph(...)`) belong.

While potentially less confounding, the `env_tools.py` package contains the `EnvTools` class that defines `env_tools` objects. No physical analogue of an `env_tools` object exists.

unit tests with a 100% pass rate. All NuSCAP unit tests were performed using the pytest [165] framework. The unit test modules and supporting data files are provided in appendix E.1. That the format and contents of various data files and packages evolved during application development. For this reason, these data files should not be replicated as faithful models to meet a user's need, but rather they are provided for reproducibility alone. Data file examples that serve as good starting points for an end user are provided in appendices D.4 and F.3.

4.1 Application Structure

The NuSCAP application relies on a series of user-generated input files to provide requisite scenario and SOS data to the five NuSCAP Python packages. This section discusses the purpose and general function of each NuSCAP package as well as the data file format and requirements.

The Python files for each package, the supporting computational environment files, and examples of user-supplied data files are provided in appendix D. These files are also electronically attached to the PDF of this manuscript. Figure A.16 shows the standard directory organization of NuSCAP modules and environment files.

4.1.1 Python Packages

The five Python packages that compose the NuSCAP application instantiate SOS elements, compose the mathematical graph of the systems and SOS, calculate the magnitudes of nuclear weapon environments, and evaluate the SOS against those environments. The weapon environment tools (`env_tools.py`) package also interacts with the nuclear weapon environment calculation programs external to NuSCAP. Here, the properties and methods found within each package and constructive relationships between the modules are discussed.

4.1.1.1 Element Package

The `element` package is the basis for creating computational objects representing personnel and equipment in the SOS, its subordinate systems, their subordinate subsystems, and the components therein. The Python package source code is available in appendix D.1.

4.1.1.1.1 Element Properties Objects of the NuSCAP `Element` class are instantiated with a number of unique properties governing their behavior. These properties are summarized in table B.4.

The analyst provides the required input values through the construction of a system data file (SDF), as discussed in §4.1.2.2. Unless otherwise noted, spaces in data entries should be avoided throughout; underscores or hyphens should be used instead. The `element.name` field is an exception to this rule–any string is valid. It is critical to the function of the NuSCAP application that the analyst adheres to the data types and units specified in table B.4 and table B.5. Any desired deviation from the standard units specified in table B.5 require changes to NuSCAP interactions with the supporting nuclear weapon environment calculators. While possible, this requires consistent application and suggests additional unit testing be performed. Furthermore, the analyst should not add to the standard dictionary keys when specifying dysfunction threshold values. While adding additional nuclear weapon environments to NuSCAP is possible, such changes require source code modification. All threshold values may be entered as a positive floating point number, positive integer, or as the string"inf" (infinity). Take note, however, that the valid range of PD values is $(0, 1]$. Entering a PD threshold value in excess of unity is the equivalent of entering "inf."

Caution should be exercised when considering the use of extrema (i.e., 0 or "inf") as dysfunction threshold values. A dysfunction threshold value of zero is almost certain to render the element dysfunctional at any reasonable distance from the point of detonation. Nevertheless, this technique may be used as an expedient way to remove a particular element from a model purposefully (e.g., the removal of one or more rockets from a rocket artillery launcher because the ordnance was expended in combat) without necessitating altering the SDF. Similarly, setting an infinite dysfunction threshold for one or more environments ensures the element will never be rendered dysfunctional because of exposure to the corresponding environment. However, several possible conditions for setting threshold values to infinity do exist:

1. setting all dysfunction threshold values to infinity for the `element` ensures its survival in the model and allows the user to focus analyses elsewhere;

2. an element may not be vulnerable to a particular nuclear weapon environment, or the element's vulnerability to a particular environment is required in a different quantity (e.g., humans are evaluated against neutron dose but not neutron fluence, so the neutron fluence threshold may be set to "inf");

3. a large SOS may include one or more very fragile elements—declaring these elements invulnerable allows the next most-fragile critical element may be investigated; or,

4. a dysfunction threshold value is unavailable for the element with respect to one or more nuclear weapon environment(s).

The analyst should apply discretion in any such circumstance and seek to understand unintended consequences

of such threshold values. Application of these extrema without intention may lead to modeling an artificially robust or vulnerable SOS.

It is essential to model accuracy that the analyst maintain a consistent Cartesian coordinate set throughout the NuSCAP model. When specifying the `element.rel_pos` and `element.heading_deg` values, this is particularly important. As NuSCAP is written, the positive z axis is a radial vector extending from the center of the Earth through the nuclear weapon detonation point. The orientation of the x and y axes is arbitrary, but generally the y axis is the true north-seeking vector. Regardless of the analyst's choice, consistency must be maintained throughout.

4.1.1.1.2 Element Methods

The `element.py` package includes three computational methods described here.

The private `element._set_thresholds(...)` method assigns the dysfunction threshold values to the `element` as it is instantiated. This method checks to ensure the user provides threshold values in the form of a dictionary and that the dictionary keys are congruent with the set of default keys. Violation of this condition raises an exception and terminates the code. Subsequently, `element._set_thresholds(...)` iterates over the user-defined threshold values dictionary and assigns the dysfunction threshold values to the `element` according to key-value pairing. Exceptions are raised for values not expressed as positive floating point numbers, positive integers, or "inf".

The private `element._set_relative_position(...)` method assigns the `element's` relative position upon instantiation. Exceptions are raised for data types other than lists, lists with lengths shorter than three, and for list entries that are neither floating point numbers or integers.

The public `element.check_functionality(...)` method compares the `element.wpn_env` dictionary values with those in the `element.thresholds` dictionary. If the magnitude of a nuclear weapon environment equals or exceeds that of its respective dysfunction threshold, the `element.functionality` value is set to zero, and `element.func_type` is set to "dysfunctional." For any such case, the `element.wpn_env` key is appended to the `element.cause_of_dysfunction` list for use in reporting the results of the analysis.

4.1.1.2 System Package

The `system.py` package is responsible for assembling `elements` into representative `system` objects capable of specified capabilities. Methods within the `system.py` package parse the SDF and the analytical scenario data file (ScDF) to create `elements`, create the `system's` mathematical graph, evaluate `elements` against nuclear weapon environments, evaluate `system` functionality and capabilities, produce visual graphs, and

create output reports at the system level. The Python package source code is available in appendix D.1.

4.1.1.2.1 System Properties

Like `element` objects, `systems` are instantiated with properties that guide their behavior and utility in NuSCAP. Properties of `system` objects are summarized in table B.6.

4.1.1.2.2 System Methods

The `system.py` package contains many methods that enable `system` graph construction and analysis.

During initialization, the `system.py` package loads the SDF and ScDF files, parses the data within, and creates `elements` to represent the system (at a macroscopic level), all its subordinate subsystems, and all components and subcomponents therein as specified in the SDF. The initialization function also sequentially executes the private methods `system._make_elements(...)`, `system._build_graph(...)`, and `system._check_degrees(...)`. According to data from the ScDF, the initialization function also creates a working directory specific to the scenario and a sub-directory specific to the system therein.

The private `system._find_elements(...)` method contains a recursive search function that reviews all subsystem dictionaries found in the SDF and identifies components within. The depth-first search continues to identify subcomponents within components and sub-subcomponents until no others are found. Each component discovered during the search is instantiated as an `element` within the `system` and is added to the `system.elements` dictionary. The closely related `system._make_elements(...)` method calls `system._find_elements(...)` to create all necessary `elements` and assigns the system's elevation to each.

The private method `system._build_graph(...)` creates a directed graph object using the NetworkX [47] Python package and populates it with a node containing each `element` of the `system` found by iterating over the `system.elements` dictionary. According to the lists in the SDF's `Structure` dictionary, administrative and terminal nodes are also created. These nodes are instantiated as `elements` with only default properties because they do not represent physical elements of the system. After creating the specified nodes, directed edges are added to connect the nodes within the graph. The SDF's `Structure` dictionary contains within it, a dictionary of edges. The `edges` dictionary contains key:value pairs that are composed of a node (key) and a list of nodes (value) to which the first is adjacent. As this dictionary is iterated over, a directed edge is added to the graph from every key node to each node in its value list. Because no edge weights are specified, all edges are weighted unity [166]. The private `system._check_degrees(...)` method evaluates the graph to ensure that all nodes are connected to at least one other node. Violations of this condition raise an exception and terminate the code.

The public method `system.calculate_ranges(...)` creates a Python MGRS object that calculates the

distance and direction from the AGZ location to the system location as specified in the ScDF. The distance calculated is rounded to the appropriate order of magnitude based on the less-precise of the two grid locations specified. Ten-digit MGRS grids are precise to within one meter; eight-digit grids are precise to within ten meters; six-digit grids are precise to within 100 meters; and, so on. The function then assigns the calculated distance (`system.range_to_gz`) and direction (`system.azimuth`). Heading (`system.heading_deg`), depth (`system.tgt_depth`), and areal density (`system.r95`) are also assigned to the `system` based on data provided in the ScDF. The function also iterates over the `system.elements` dictionary and assigns elevation, range, depth, areal density, azimuth, and heading data to all `elements` of the `system`.

The public method `system.evaluate_nodes(...)` iterates over all `elements` within the `system` and calls the `element.check_functionality(...)` method for each node in the `system` graph (excluding administrative and terminal nodes). All edges incident with any node containing a dysfunctional `element` are removed from the system graph.

The public `system.evaluate_system_functionality(...)` method calls the `networkx.has_path(...)` function and directs it to traverse the `system` graph between the terminal nodes. The `networkx.has_path(...)` function is a subroutine of the `networkx.shortest_path(...)` function [166]. It attempts to traverse the `system` graph according to Dijkstra's algorithm [142, 166]. Edges removed because of incidence with dysfunctional nodes are treated as having infinite edge weight. If a viable path remains between the `system` graph's terminal nodes, `networkx.has_path(...)` returns `True`. Else, it returns `False`; `system.functionality` is set to zero, and `system.func_type` is set to "dysfunctional."

The public `system.evaluate_capabilities(...)` method calls the `networkx.has_path(...)` function to traverse user-specified paths through the `system` graph. These paths are specified by accessing data within the `capabilities` dictionary of the SDF. For each capability stored in the dictionary, the subordinate capability bin structure (a list of dictionaries) is iterated over beginning with the most capable bin. Within each bin structure, three lists of equal length are accessed:

1. `Begin Node`,
2. `End Node`, and
3. `Has Path`.

The sequential entries within each list compose a set of graph traversal instructions (e.g., `[X, BB3, True]`) for the method. For each set of instructions, `system.evaluate_capabilities(...)` calls the `networkx.has_path(...)` method to attempt the specified path. If the results the traversal attempts for all `Begin Node` and `End Node`

pairs match the corresponding conditions specified in the bin structure's `Has Path` list, the bin represents the highest capability state. Thus, the name of the bin (key) is recorded as the maximum capability level in the `system.residual_capabilities` dictionary. Otherwise, traversal of the paths specified in the subsequent bin(s) are attempted until agreement is found between a set of specified path conditions and the corresponding results of the `networkx.has_path(...)` searches. This process occurs for all capabilities included in the SDF.

When composing capability bin structure in the SDF (see §4.1.2.2), the analyst should take note to ensure the second bin defined for each capability begins with "NOT POSSIBLE." Violations of this requirement raise an exception and terminate the code. Contrary to §3.2.3.3, it was discovered during unit testing that "NOT POSSIBLE" conditions may also fulfill the less-specific criteria for a degraded state. This could lead to erroneous capability reporting if the bins are investigated in the order described in §3.2.3.3. Also, this modification has the benefit of increasing computational efficiency by not requiring inspection of interstitial degraded states bins when the capability is truly not possible.

Consider `Degraded Capability Bin 1` within `First Capability` found in listing D.7. In this case the `system.evaluate_capabilities(...)` method will attempt to traverse the `system` graph from `AA` to `DD` and compares the `networkx.has_path(...)` result with the Boolean value `true` from the first entry in the `Has Path` list. Then, it attempts to traverse the `system` graph from `BB` to `EE` and compares the `networkx.has_path(...)` result with the Boolean value `false` found in the second entry of the `Has Path` list. If the results of both traversals match both Boolean conditions specified, that bin represents the maximum capability state. Otherwise, the `system.evaluate_capabilities(...)` method will continue and attempt the paths specified for `Degraded Capability Bin 2`.

The public `system.save_graph(...)` method allows the user to save a PDF image of the `system` graph after construction and/or after evaluation by the `system.evaluate_nodes(...)` method. The `system.save_graph(...)` method calls the `networkx.draw(...)` function to produce the `system` graph image. Such images produced after calling the `system.evaluate_nodes(...)` method are colored according to the functionality of each node. Functional nodes remain the default color; dysfunctional nodes are colored black with white text. The PDF image is saved to the working directory as "`<YYYYMMDD>_<hhmmss>_<system_name>_graph.pdf`." Prior to execution, the user should access the source code and confirm the `dot.exe` executable is accessible in the system path. Failure to do so may result in unexpected errors.

The public `system.report(...)` method creates a human-readable report of the system analysis in JSON format. The timestamped report includes the system's name and the name of the scenario as indicated in the SDF and ScDF, respectively. Overall system functionality type (`system.func_type`) and the residual capabilities are reported with the maximum bin for each capability explicitly called out. The functionality type

of each element within the system is provided along with the causes(s) of dysfunction for all dysfunctional elements. The file is saved as "<YYYYMMDD>_<hhmmss>_<system_name>.out.json" in the system's sub-directory within the working directory.

4.1.1.3 System of Systems Package

NuSCAP's sos.py package constructs an integrated SOS architecture by combining all system graphs into a single, cohesive SOS model according to the user-specified relationships in the SOS data file (SOSDF). Methods in this package parse the ScDF and the SOSDF, instantiate all listed systems as system objects, compose the sos mathematical graph, call external processes to calculate nuclear weapon environment values, check the functionality of the sos, evaluate its capabilities, and produce a SOS-level analysis report. The Python package source code is available in appendix D.1.

4.1.1.3.1 SOS Properties Like the element and system objects that compose them, sos objects are instantiated with properties that define their behavior and utility in NuSCAP. Properties of sos objects are summarized in table B.7.

4.1.1.3.2 SOS Methods In addition to the initialization function, the sos.py package contains eight methods that support the construction and analysis of the SOS model. The sos.__init__(...) function iterates over the Systems dictionary within the SOSDF and instantiates a system object for each constituent system within the SOS. As each system is instantiated, the system.__init__(...) function creates the corresponding system graph.

The public sos.construct_sos_graph(...) method composes the integrated sos graph from the now-present system graphs. An empty sos graph is instantiated as a directed networkx.DiGraph object. Each administrative and terminal node specified in the SOSDF are instantiated as elements. A node containing each of these is added to the sos graph. Then, sos.construct_sos_graph(...) calls the networkx.compose(...) function by which it adds all existing system graphs to the sos graph. Finally, structure and capability edges are added to the sos graph. The related public sos.show_sos_graph(...) method displays the graph to the screen for user inspection.

The private sos._get_environments(...) method instantiates a NuSCAP.env_tools object to which it supplies the sos name and ScDF path. The method then calls three public NuSCAP.env_tools methods (i.e., env_tools.run_pdcalc(...), env_tools.run_snec(...), and env_tools.run_mcnp(...)) that execute nuclear weapon environment calculations using PDCALC, SNEC, and the MCNP code, respectively. The

methods and subroutines involved in these calls are discussed further in §4.1.1.4.2.

The public method `sos.evaluate_sos(...)` calls the `system.calculate_ranges(...)` method to ascertain the distance from each system to the AGZ and subsequently executes the `sos._get_environments(...)` method. At the completion of this function call, all `elements` of the `sos` have been assigned nuclear weapon environment values based on calculations performed by the `env_tools.py` package. Next, the `sos.evaluate_sos(...)` method iterates over all `systems` found in the `sos.systems` dictionary, and sequentially calls four methods on each `system` in the `sos`:

1. `system.evaluate_nodes(...)`,
2. `system.evaluate_system_functionality(...)`,
3. `system.evaluate_capabilities(...)`, and
4. `system.report(...)`.

In doing so, all `systems` and `elements` composing nodes of the `sos` graph are assigned functionality values commensurate with the nuclear weapon environments to which they have been exposed in the model. Next, `sos.evaluate_sos(...)` iterates over all nodes in the `sos` graph, identifies all nodes containing dysfunctional `elements`, and removes all edges from each such node.

The public `sos.check_sos_functionality(...)` method attempts to traverse the `sos` graph between its terminal nodes by calling the `networkx.has_path(...)` method. If the result is `False`, `sos.functionality` is made zero, and `sos.func_type` is made "dysfunctional."

The public `sos.evaluate_sos_capabilities(...)` method calls the `networkx.has_path(...)` function to traverse user-specified paths through the `sos` graph. These paths are specified by accessing data within the `SOS capabilities` dictionary of the SOSDF. For each capability stored in the dictionary, the subordinate capability bin structure (a list of dictionaries) is iterated over beginning with the most capable bin. Within each bin structure, three lists of equal length are accessed:

1. `Begin Node`,
2. `End Node`, and
3. `Has Path`.

The sequential entries within each list compose a set of graph traversal instructions (e.g., `[X, BB3, True]`) for the method. For each set of instructions, `system.evaluate_capabilities(...)` calls the `networkx.has_path(...)`

method to attempt the specified path. If the results the traversal attempts for all `Begin Node` and `End Node` pairs match the corresponding conditions specified in the bin structure's `Has Path` list, the bin represents the highest capability state. Thus, the name of the bin (key) is recorded as the maximum capability level in the `system.residual_capabilities` dictionary. Otherwise, traversal of the paths specified in the subsequent bin(s) are attempted until agreement is found between a set of specified path conditions and the corresponding results of the `networkx.has_path(...)` searches. This process occurs for all capabilities included in the SOSDF.

When composing capability bin structure in the SOSDF (see §4.1.2.3), the analyst should take note to ensure the second bin defined for each capability begins with "NOT POSSIBLE." Violations of this requirement raise an exception and terminate the code. Contrary to §3.2.3.3, it was discovered during unit testing that "NOT POSSIBLE" conditions may also fulfill the less-specific criteria for a degraded state. This could lead to erroneous capability reporting if the bins are investigated in the order described in §3.2.3.3. Also, this modification has the benefit of increasing computational efficiency by not requiring inspection of interstitial degraded states bins when the capability is truly not possible.

The public `sos.save_sos_graph(...)` method may be called before or after the `sos.evaluate_sos(...)` method to save a PDF image of the SOS graph at its present condition. The `sos.save_sos_graph(...)` method calls the `networkx.draw(...)` function to produce an image of the `sos` graph. If called after completion of the `sos.evaluate_sos(...)` method, the graph image is colored according to the functionality of each node. Functional nodes remain the default color; dysfunctional nodes are black with white label text. The PDF image is saved to the scenario working directory as "`<YYYYMMDD>_<hhmmss>_<sos_name>_graph.pdf`."

The public `sos.sos_report(...)` method creates a human-readable report of the SOS evaluation in JSON format. The timestamped report includes the SOS's name and the name of the scenario as indicated in the SOSDF and ScDF, respectively. Overall SOS functionality type (`sos.func_type`) and the residual capabilities are reported with the maximum bin for each capability explicitly called out. The functionality type of each `system` within the `sos` is provided along with the causes(s) of dysfunction for all dysfunctional `systems`. Note the cause(s) of dysfunction are populated only for the `element` representing the overall system, not all the `elements` within the `system`. The file is saved as "`<YYYYMMDD>_<hhmmss>_<sos_name>.out.json`" in the scenario working directory.

4.1.1.4 Nuclear Weapon Environment Tools Package

The `env_tools.py` package formats user-provided data into forms usable by the three nuclear weapon environment calculator programs employed in NuSCAP, accesses the external programs to run nuclear weapon

environment calculations, parses the output data from those calculations, and assigns weapon environment values to `elements` of the `sos`. The Python package source code is available in appendix D.1.

4.1.1.4.1 EnvTools Properties `EnvTools` class objects posses properties common to other NuSCAP objects with unit conversions applied to support their use by external nuclear weapon environments tools. The `env_tools` object properties are summarized in table B.8.

4.1.1.4.2 EnvTools Methods The methods of this package each correspond to a specific nuclear weapon environment calculation program. Each method is discussed in the paragraphs that follow as they pertain to the individual nuclear weapon environments calculator. Comments regarding acquisition and use of the programs are provided.

4.1.1.4.2.1 PDCALC The `env_tools.py` package accesses PDCALC[2] through the public `env_tools.run_pdcalc(...)` method. This method iterates over all nodes in the `sos` graph, ignoring administrative and terminal nodes. For each `sos` graph node with a valid VNTK provided, a `PDCALC` Python object is created and the `PDCALC.calcPOD(...)` method is executed. From this method, a PD for the `element` in the node is calculated and assigned to the `element.wpn_envs` dictionary. For all nodes, a `PDCALC` object is instantiated to calculate peak blast pressure values. In this case, `env_tools.run_pdcalc(...)` calls the `PDCALC.peakOverPress(...)` and `PDCALC.peakDynPress(...)` methods to which the weapon yield, ground range from AGZ to the element, and the weapon HOB are provided. These functions return the peak static overpressure and peak dynamic pressure magnitudes, respectively. The calculated values are assigned to the `element.wpn_envs` dictionary, accordingly.

The PDCALC software was provided to the author including a Python wrapper for the original PDCALC FORTRAN subroutines. The Python wrapper relies on Microsoft® Windows®-specific dynamic link library (`*.dll`) files. While it is certainly possible that one may produce an appropriately structured Python code to access PDCALC from another operating system, NuSCAP only offers compatibility with PDCALC through Windows® at this point. Attempting to call the `env_tools.run_pdcalc(...)` method on a computer using other than a Windows® operating system will raise an exception and terminate the code. The PDCALC directory containing the `PDCALC.py`, its associated `__init__.py` file, and the `PDCALC.dll` file should be hosted within the NuSCAP sub-module directory (see fig. A.16).

[2]The PDCALC code and Python wrapper are not included in this document. The PDCALC software may be requested from the PDCALC Program Manager at USSTRATCOM/J593, Attention: PDCALC Program Manager, 900 SAC Boulevard, Suite NL2.132, Offutt Air Force Base, Nebraska 68113-6300; or by phone at (402) 912-5738.

4.1.1.4.2.2 SNEC NuSCAP's `env_tools.py` package accesses the LANL SNEC[3] tool through the public `env_tools.run_snec(...)` method. First, this method constructs a dictionary of elevations and ranges to AGZ represented by the `elements` within the `sos`. That is to say, a key is created for every ground elevation at which an `element` exists in the model. To that key is added a list of the ranges from AGZ for which `elements` at that elevation exist. Then, a SNEC input file is written according to the format shown in listing D.10. The file specifies the weapon yield, HOB, and atmospheric visibility followed by ordered pairs in the form (`range_to_GZ`, `elevation`). This file name written to a batch file according to the format shown in appendix D.5.3. Next, `env_tools.run_snec(...)` invokes the `subprocess.call(...)` method to execute the batch file using a JAVA runner script provided with the SNEC tool.

The calculation process creates an output file populated with nuclear weapon environment magnitudes of interest (i.e., windspeed and thermal fluence) according to the elevation and ground range for which the data is calculated. An example output file is shown in listing D.11. The `env_tools.run_snec(...)` method accesses the output file and searches nuclear weapon environments text data stored within using the `re.search(...)` method based on elevation and range to AGZ. The `env_tools.run_snec(...)` method constructs a dictionary with this data using elevations as the keywords that hold subordinate dictionaries using ranges to AGZ as keys. Within these is yet another layer of dictionaries where thermal fluence and windspeed data are stored. Finally, the method iterates once again over all `elements` in the `sos` and assigns thermal fluence and windspeed values to the `element.wpn_envs` dictionary for each `element` with corresponding elevation and ground range pairs.

A custom multiple-effects batch interface was constructed for SNEC at the author's request [167]. Dr. John St. Ledger is the author of SNEC and the custom JAVA batch interface. As one reviews the `EnvTools.py` file, they will note several large commented sections of code. The SNEC tool offers access to a number of nuclear weapon environment calculations that are not required because of the desire to incorporate both PDCALC and MCNP in NuSCAP. Should a future analyst wish to employ these functions, they are available by removing the comments around those particular sections of code. These additions will, however, require modification to associated functions in other NuSCAP packages (e.g., `element.py`, `system.py`).

4.1.1.4.2.3 MCNP6.2 The MCNP code[4] is accessed by NuSCAP through three private methods:

[3]The SNEC tool is one of a suite of nuclear weapon data calculators authored by Dr. John St. Ledger, colloquially known as the "John St. Ledger tools" or "JSL tools." Requests for this software to support official government business should be made by contacting the Chief Scientist for Nuclear Weapon Effects at Los Alamos National Laboratory at `weapon_effects@lanl.gov`.

[4]The MCNP code requires each individual user to possess a valid license. The license and software are available through the Radiation Safety Information Computational Center (RSICC) at Oak Ridge National Laboratory (ORNL) at `https://rsicc.ornl.gov/Default.aspx`. Additional information about requesting the MCNP code is available on the MCNP code website at `https://mcnp.lanl.gov`.

1. `env_tools._build_mcnp_input(...)`,
2. `env_tools._execute_mcnp(...)`, and
3. `env_tools._parse_mcnp_output(...)`,

and the public `env_tools.run_mcnp(...)` method. Certain terms used here are unique to the MCNP code. Extensive discussion of these is provided in [22, 152]. Nevertheless, the general method and data used here should support neutral particle transport calculations using other computational codes.

The `env_tools._build_mcnp_input(...)` method constructs MCNP6.2 input decks using data from the ScDF and SOSDF. This method first creates input and output working directories for MCNP6.2 calculations within the scenario working directory, card and data subdivision lines, title and message cards, and header comments. Subsequently, `env_tools._build_mcnp_input(...)` iterates over the contents of the `Threat Weapon Data` dictionary within the ScDF to identify particle types by the presence of keywords `Neutron Leakage Spectrum` and/or `Photon Leakage Spectrum`. Next, according to the particle type, the transport physics card is composed along with the `NPS` card that specifies the number of particle histories to be run in the calculation. The process that follows is performed for neutrons and/or photons according to the threat weapon data specified in the ScDF.

The method then performs set of geometry calculations that determines the absolute position (in Cartesian coordinates with units of centimeters) of every element relative to the weapon detonation position—which serves as the origin of the 3-D model space. These calculations consider the relative position of each element to the bottom, center face of its parent system, the MGRS location of the parent system, and the heading toward which the system is oriented as compared to the MGRS location of AGZ and the HOB of the weapon. Because of the simplified geometry represented in this initial work, a horizontal plane passing through the AGZ point serves as the demarcation between the Earth and the atmosphere along the z axis. An RPP below ($-z$ direction) the AGZ point represents the Earth; an RPP above ($+z$ direction) the AGZ point represents the atmosphere (air). Because of this simplification, it is possible to instantiate `elements` at vertical positions below the earthen surface. To prevent unfair treatment of these `elements` by the MCNP code, `env_tools._build_mcnp_input(...)` specifies that all `systems` with an elevation below that of the AGZ are translated in the positive z direction to the AGZ elevation plus a 10.1 cm buffer. In this way, the relative positions of all `elements` within such `systems` are preserved. Once the absolute position of each element is calculated, the `element.abs_pos` values are updated, accordingly. The physical extents of the model are calculated according to the position of elements farthest displaced in the x, y, and z from AGZ with the addition of five mean-free-path lengths relative to a 2 MeV photon in the air or earth material. From these

calculations, two surface cards are constructed to define the RPPs accordingly.

The definition of cell cards follows based on the transport materials and the material density defined in the `Transport Materials` dictionary of the ScDF. A surrounding "particle graveyard" cell is created outside the extents of the Earth and atmosphere cells. Corresponding material definition cards are subsequently defined also using data supplied in the `Transport Materials` dictionary of the ScDF according to the ZAID fraction method discussed in [152, §5.6.1].

According to the particle type involved, source definition (`SDEF`) cards are created using energy bins, probabilities, and source information and source probability options specified in the `Neutron Leakage Spectrum` or `Photon Leakage Spectrum` dictionaries of the `Threat Weapon Data` dictionary supplied in the ScDF. Energy bin upper limits are provided in units of MeV with corresponding probabilities given in mol·MeV^{-1}·kt^{-1}. Source information and probability options are also defined according to the MCNP manual [152, §5.8.2–5.8.3]. During this process, energy bins and their corresponding probability entries are checked to ensure they are equal in number (i.e., each bin has a corresponding probability value provided), and the energy bin structure is verified to increase monotonically. Violations of either of these conditions raise an exception and terminate the code. The detonation source is placed at the origin (0,0,0) in the MCNP model space. Each source history is weighted according to the product of Avogadro's constant, the weapon yield in kt, and the neutron or photon yield of the weapon in mol·kt^{-1}, as specified in the `Threat Weapon Data` dictionary of the ScDF.

Following the creation of `SDEF` card entries, a random number generator (`rand`) card is created, and then tally cards are formed. An individual tally is used to represent each `element` in the model. To distinguish between tallies, a series of counters are initialized in this portion of code. These counters serve as tally number prefixes to distinguish between NuSCAP's tally categories out of convenience only. This is not a requirement or standard convention in the MCNP code. The prefixes indicate the tally quantity according to the following scheme:

1. Tally numbers beginning with "1" represent a 1 MeV-equivalent neutron fluence tally.
2. Tally numbers beginning with "2" represent a tally calculating neutron dose to equipment.
3. Tally numbers beginning with "3" represent a tally calculating neutron dose to humans.
4. Tally numbers beginning with "4" represent a tally calculating photon dose to equipment.
5. Tally numbers beginning with "5" represent a tally calculating photon dose to humans.

As `env_tools._build_mcnp_input(...)` iterates through the nodes of the `sos` graph, each `element` is identified as human or equipment according to its `element.el_type` property. Based on this distinction, the method creates the appropriate tally number prefix for each `element` based on the designation scheme presented. An `F5` tally card is created for each specified tally. The tally card includes the tally number (incremented by ten after each `element` is addressed), the absolute position of the `element` in Cartesian coordinates with units of centimeters according to the `element.abs_pos` property, and a specified 10 cm radius for the exclusion sphere existing around the point detector in computational space. A corresponding tally comment card is created specifying the `element's` name and the tally quantity. This allows the `env_tools._parse_mcnp_output(...)` method to maintain the relationship between an `element` and its tally data.

Subsequently, tally modification cards are defined. NuSCAP employs three tallies that use dose energy (`DE`) and dose function (`DF`) cards. These cards allow NuSCAP to employ point-wise flux-to-dose conversion factors, modifying the value of tallies in categories 1, 3, and 5. Defined in the `Neutron Response Functions` or `Photon Response Function` dictionaries of the ScDF's the `Threat Weapon Data` dictionary, the `DE` card defines the energy structure of the response function the `DF` card defines the corresponding coefficients by which the tally score is multiplied to achieve the desired output units according to the energy of the particle responsible for the score. Tally categories 2 and 4 employ tally multiplier (`FM`) cards. These cards are constructed with data provided in the same ScDF dictionaries as are `DE` and `DF` cards. The `FM` card data used in NuSCAP is generated for elemental silicon using the MatMCNP tool [160, 161]. These multiplier cards allow conversion of tally data to equipment dose expressed in rad(Si). For each tally, a corresponding `DE` and `DF` or `FM` card is created using the same tally number.

A tally time bin structure is created via a `T` card to allow for dose rate calculations. The `env_tools._build_mcnp_input(...)` method calculates the slant range from the point of detonation to the nearest and most distant elements in the model. Time bins are then constructed using zero as the minimum value followed by a bin limit equal to the amount of time a photon requires to travel from the source to the nearest element (tally). One hundred logarithmically spaced bins follow that are terminated by a maximum bin limit equal to the amount of time an unscattered thermal neutron requires to travel from the source to the most distant element. Finally, the MCNP input deck is written to disk in the MCNP input working directory according to the standard format specified in [152, chapter 4].

The `env_tools._execute_mcnp(...)` method accesses the `MCNP Threads` and `MCNP path` data specified in the ScDF and then calls the Python `subprocess.run(...)` command to run the MCNP6.2 executable. This operation is performed sequentially for each input file created for the scenario. Output files (`*.mcnp.out`)

and MCTAL files (*.mcnp.mctal) are created during the calculations according to the names provided in the message card; they are saved in the MCNP output working directory.

NuSCAP's env_tools._parse_mcnp_output(...) method calls functions within the Python mcnptools [168] package to read the MCTAL files produced by env_tools._execute_mcnp(...). In doing so, the mcnptools.Mctal.GetValue(...) function extracts the each tally score from the MCTAL file. The mcnptools.Mctal.SummaryString(...) function extracts the corresponding tally comment that links each tally to the element it represents. As each tally value is read, it is stored in a temporary dictionary by element name and subsequently by tally type. Next, for tallies in category 4 (i.e., photon dose rate), the method calculates the width of all time bins for the tally and divides the corresponding tally score by the width of the individual time bin. The maximum of the resulting values for each of these tallies is recorded in the temporary dictionary as the gamma ray dose rate. After env_tools._parse_mcnp_output(...) iterates over all tallies for all elements and the maxima dose rates have been calculated, the method assigns the appropriate wpn_envs values (i.e., neutron fluence, neutron dose, gamma ray dose, and gamma ray dose rate) to each element node in the SOS graph.

The sole public method in this package, env_tools.run_mcnp(...), sequentially calls the three previously defined methods: env_tools._build_mcnp_input(...), env_tools._execute_mcnp(...), and env_tools._parse_mcnp_output(...). Doing so compiles the required MCNP6.2 input files, executes the calculation, and parses the outputs—ultimately assigning neutral particle radiation environments to all elements within the sos.

4.1.1.5 NuSCAP Package

The (main) NuSCAP.py package is responsible for parsing user command line arguments and calling NuSCAP subroutines to execute the fully automated SOSVA process. The NuSCAP.py package does not possess any unique properties or methods, rather it accesses methods and properties defined elsewhere in the application. The Python package source code is available in appendix D.1.

NuSCAP instantiates an sos object according to the NuSCAP.sos package providing to it the sos.name, sos.sosdf, and sos.scdf arguments from the user's command line inputs. When executed, NuSCAP.py sequentially performs the following functions:

1. sos.construct_sos_graph(...),
2. sos.show_sos_graph(...),
3. sos.evaluate_sos(...),

4. `sos.save_sos_graph(...)`,

5. `sos.check_sos_functionality(...)`,

6. `sos.evaluate_sos_capabilities(...)`, and

7. `sos.sos_report(...)`.

At successful conclusion of the analysis run, the user's display shows the message: "`The NuSCAP™ analysis is complete!`"

4.1.2 User-generated Inputs

A user must provide the NuSCAP application with sufficient data to create the SOS model and evaluate it against the desired scenario. It is preferable to establish a working directory within which all input and output files created during the NuSCAP application run are stored. This structure along with the type and format of all input files are discussed here. The expected output file types and formats are discussed in §4.2.2.

Note that other than entries explicitly called "free-text" entries, all data input data produced for NuSCAP should avoid the use of spaces, reserved characters (e.g., ., \, /), and non-standard characters (i.e., &, !). Hyphens, underscore characters, and alphanumeric characters are acceptable.

4.1.2.1 Suggested Directory Structure

Figure A.17 provides a graphical guideline suggestive of an appropriate directory structure. Note that NuSCAP modules will create system directories (e.g., `/M3A3_CFV`), MCNP working directories (e.g., `/M3A3_CFV/MCNP`) with subdirectories designated for input and output files, and SNEC working directories (e.g., `/M3A3_CFV/SNEC`) with subdirectories designated for input and output files. Should the user choose to follow this model, the `Users` directory, individual user directories (e.g., `Dragon_5`), the `Scenarios` directory, the `Systems` directory, and the `System_of_Systems` directory will all require creation prior to using the NuSCAP application.

The idea behind creating stand-alone catalogs of systems, systems of systems, and scenarios is that the individual systems (e.g., a HMMWV) may be part of various systems of systems (e.g., a CBRN reconnaissance element or an infantry platoon). Defining this system once and referring to the single SDF reduces overhead effort and computational storage allocation. Likewise a specific system of systems (e.g., an infantry platoon) may be analyzed in various different scenarios (e.g., a low-yield tactical nuclear detonation or a high-altitude electromagnetic pulse (HEMP) strike). Maintaining a catalog of scenarios is also worthwhile from an

operational planning perspective. By inserting a tank platoon into the infantry platoon's scenario, a planner or commander can better understand the effects of that scenario on different SOS at their disposal.

4.1.2.2 System Data Files

Each system included in the SOS being studied must be codified using its own system data file. All SDFs are composed using the JSON syntax and use the file extension "`.sdf.json`." An exemplar SDF shell is provided in appendix D.4.1.

4.1.2.2.1 Header The SDF begins with the keyword `HEADER COMMENTS` at which the analyst is encouraged to provide a brief description of the system. The official nomenclature, model number, and manufacturer are appropriate entries here, as are references to any technical manuals used in the creation of the model.

4.1.2.2.2 System The next keyword, `System` begins the formal system definition. Within this dictionary is the keyword corresponding to the system's name (e.g., `This_System_Name`). This keyword must be unique to the system. For instance, if a tank platoon is the SOS in question, four tanks are required. Each tank's SDF must provide a name unique to that individual system (e.g., Dealer 21, Dealer 22, Dealer 23, and Dealer 24). While it is always recommended practice to avoid spaces and special characters, they are allowed in this field. Within the system's dictionary are five subordinate entry fields: `ID`, `type`, `subtype`, `color`, `VNTK`, and `thresholds`.

The `ID` keyword presents the analyst with an opportunity to enter additional details about the system as desired. This free-text field may be omitted entirely if it is not needed. The user must supply an entry to the `type` keyword—either "human" or "equipment" based on the nature of the system.

The optional `subtype` field corresponds to a yet more refined definition of the system. These entries are employed in the case study presented in chapter 5 to expedite the assignment of threshold values by an auxiliary utility script. Suggested values include "personnel," "mechanical," "electrical," "fiber optics," "antenna," "weapon," and "ordnance."

The optional `color` field corresponds to a string entry of the formats accepted by the Graphviz visualization software: color name (string), RGB, RGBA, HSV, or HSVA [169]. The color entered at this keyword is the fill color used to represent nodes of the `system` in the system- and SOS-level visual graphs. If no color is specified by the user, the color value defaults to the hexadecimal RGB value of "#355E93."

The user must supply a value to the `VNTK` keyword. This value must be either `null` or a string in the VNTK, 2-VNTK, or G-VN format [17].

The `thresholds` keyword also corresponds to a dictionary containing ten entry fields: `static overpressure`, `dynamic pressure`, `windspeed`, `thermal fluence`, `total dose`, `neutron dose`, `neutron fluence`, `gamma ray dose`, `gamma ray dose rate`, and `PD`. Values are required for each of these keywords. The type of entry and the standard units for each are defined in table B.5. It is of note that different units of measure may be substituted for the default units in NuSCAP. These changes (e.g., to displacements per atom (DPA) in lieu of 1 MeV-equivalent neutron fluence) will require non-trivial modifications to the NuSCAP source code and may require the use of additional, external computational tools not considered in this work.

4.1.2.2.3 Subsystems Stepping back out to the indent level of the `System` keyword, the next input field corresponds to the `Subsystems` keyword. Within this dictionary are entries for each subsystem and each component that, together, compose the entire system. Each individual subsystem and component must have unique names just as the system must. Spaces and special characters are allowed in this field, too. While tedious, this requires the development and maintenance of more-or-less creative bookkeeping methods for the constituent elements of large system and SOS models. For large models, a consistent naming convention is important to reduce ambiguity and maintain common definitions among all involved in the analysis processes. Each named subsystem keyword (e.g., `Subsystem_1_Name`) corresponds to a dictionary with the same entries as the system: `ID`, `type`, `subtype`, `VNTK`, and `thresholds`. These fields are populated in an identical manner.

An additional, and optional, entry field is the `Components` keyword. This keyword holds a dictionary of the components that compose the subsystem. Each component requires a unique name and the same entries found at the subsystem level: `ID`, `VNTK`, `thresholds`, and `Components`. The components entry is likewise optional here, and if populated contains the subcomponents of the component. This nesting procedure may be carried out for as many subsystems, components, and subcomponents as are required to adequately describe the system in accordance with the principles discussed in §3.2.3.

Note that in listing D.7, each entry where `<a_number>` is shown requires a numerical entry; likewise where `<str_VNTK>` appears, a valid VNTK string is required.

4.1.2.2.4 Capabilities Returning to the `System` keyword level, the next input field is the `capabilities` keyword. Within this dictionary are keywords corresponding to each system capability. Each capability within a system should be uniquely named, but it need not be universally unique. For example, the tank named Dealer 21 may have the capability "Fire Main Gun." The tanks Dealer 22, Dealer 23, and Dealer 24 may also have the "Fire Main Gun" capability without creating a conflict with evaluating Dealer 21. This is true because while the system, its subsystem, and its components all become `element` objects within the same `sos`

graph, capabilities are never instantiated as computational objects. Rather, capabilities are properties of each individual `system`. Also, the name of a capability is a free-text field where spaces and special characters are permitted. Within each named capability (e.g., `First Capability`) is a list of dictionaries. Each dictionary corresponds to a degraded-states capability bin as described in §3.2.3.3.

A minimum of two capability bin dictionary entries are required for each capability. The first bin (e.g., `Most Capable Bin`), whatever it is named, should represent the undamaged capability state. The second bin name must begin with the phrase "NOT POSSIBLE" and should represent a condition where the capability is no longer available because of damage sustained during the nuclear detonation. It was discovered during development and unit testing that checking the most-capable bin followed immediately by the least-capable bin in the structure is more computationally efficient and avoids erroneously identifying residual capabilities where one does not exist. If the capability is completely unavailable, it is possible for an analyst to inadvertently define an intermediate degraded state path that meets the function's criteria thus causing the evaluation to terminate prematurely. If multiple conditions may cause a complete loss of the function, additional "NOT POSSIBLE" bin(s) may be defined. Following these, the intermediate degraded states bins are listed. An example of this paradigm as applied to a SOSDF is available in appendix D.4.2 (see `Capability 2 Name`).

Within each capability dictionary are four entry fields: `Begin Node`, `End Node`, `Has Path`, and `Comment`. The values corresponding to the `Begin Node` and `End Node` keywords are lists of `system` graph nodes (usually terminal nodes or administrative nodes). The value corresponding to `Has Path` must be a list of Boolean entries equal in length to the `Begin Node` and `End Node` lists. The `Comment` field is a free-text field where a short description of the bin is appropriate. This is the human-readable description of the maximum capability printed to the output file when the `system.report(...)` method is called. By declaring the beginning and ending node pair along with the Boolean `Has Path` condition, the analyst instructs the `system.evaluate_capabilities(...)` method to traverse the system graph from the `Begin Node` to the `End Node` and compare the result from the `networkx.has_path(...)` function with the `Has Path` condition. If all the Boolean values returned by the function match those specified in the `Has Path` list, this bin represents the maximum capability level.

As many paths as necessary may be specified to adequately define a bin. This set of instructions is repeated for every capability for which the analyst desires to evaluate and for every bin therein.

4.1.2.2.5 Structure Again at the `System` keyword level, the next entry is `Structure`. The `Structure` field is a dictionary containing the keywords `Admin Nodes`, `Terminal Nodes`, and `Edges`.

At the keyword `Admin Nodes` is a list of the administrative nodes needed to form the `system` graph and

between which capabilities are typically measured. This list may contain as many entries as necessary to appropriately evaluate the `system` graph. Because administrative nodes are instantiated as `elements` and become part of the unified `sos` graph, all administrative nodes must have unique names. A double-alphabetic character naming convention is suggested. Names such as `AA D21` and `BB D21` establish administrative nodes `AA` and `BB` unique to the Dealer 21 tank, for example. These strings are free-text fields where spaces and special characters are permitted.

The `Terminal Nodes` keyword corresponds to a list of exactly two entries. In keeping with the standard NuSCAP naming convention, it is suggested the beginning terminus name begins with "`X`" and the ending terminus name begins with "`XX`." Like administrative nodes, these nodes must also have unique names as they, too, will become instantiated as Elements within the SOS graph. Thus, a naming convention such as `X D21` and `XX D21` for the Dealer 21 tank is appropriate and encouraged.

The `Edges` keyword corresponds to a dictionary that contains keywords representing the various elements of the system with corresponding lists of other nodes to which the key node is adjacent. The key node is connected to the value nodes by directed edges beginning at the key node and ending at each value node. For instance, in listing D.7, three directed edges begin at `This_System_Name`. One edge terminates at `Subsystem_1_Name`, another at `Subsystem_2_Name`, and the final one at `Subsystem_3_Name`. The node names included in the `Structure` dictionary must exactly match the system, subsystem, and/or component names specified in the SDF. The structure an analyst defines here must follow the system model generated by following the process described in §3.2.3. This structure should also create a DAG. That is, a continuous path must exist between the terminal nodes when the system is in its original state, and all branches within the graph should end at the downstream terminus (e.g., `XX`). See appendix F.2 for example figures.

4.1.2.2.5.1 The System Node Note in the example structure in listing D.7 that the system node itself is adjacent from the beginning terminus, making it a single point of failure. This is done intentionally in every SDF with the assumption that the system itself may possess overarching dysfunction thresholds (e.g., VNTK/PD), which when exceeded, render the entire system dysfunctional. Adhering to this paradigm is suggested.

4.1.2.2.6 Footer Footer data is entirely optional, but the standard practice in NuSCAP is to identify the system model developer and any subsequent maintainers of the SDF here. Other appropriate information may include contact information for these individuals.

4.1.2.3 System-of-Systems Data File

Similar to each system, each SOS must be uniquely defined according to its own system-of-systems data file. The SOSDF also follows the JSON syntax and uses the file extension "`.sosdf.json`." An exemplar SOSDF shell is provided in listing D.8. Because of the integral nature of the SOS package, the SOSDF reflects essentially the same structure as the SDF but with a lesser degree of detail required.

4.1.2.3.1 Header The SOSDF header should include a brief description of the SOS being modeled. Pertinent data here might include the type of military unit the SOS represents, the MTOE number and date of retrieval, and any pertinent doctrine referred to in the model development process.

4.1.2.3.2 System of Systems The first keyword following the header data, `System of Systems`, requires only one entry: a dictionary to which the keyword is the unique name of the SOS. The name should be unique in that it is different than the systems, subsystems, and components that compose it. While ill-advised, it is allowed to have the same name as a SOS defined in an altogether separate SOSDF. In the sample listing, this name is `Your_SOS_Name`. The value corresponding to this keyword is a dictionary containing the optional keyword `ID` to which the user may add more specific data about the SOS not included in the header (e.g., a particular unit type, name, or designation).

4.1.2.3.3 Systems Returning back to the `System of Systems` indent level, the next keyword is `Systems`. The `Systems` value is a dictionary in which the keywords are names of the systems that compose the SOS. To each of these system names is assigned a dictionary with a single keyword `SDF Path` for which the value is the absolute system path to the corresponding SDF. The system names used as keywords here should exactly match the names given them in the named SDF.

4.1.2.3.4 Capabilities The next keyword at the `System of Systems` indent level is `SOS capabilities`. This dictionary is of identical composition to the `capabilities` dictionary of the SDF. Also like in the SDF, two entries are required for each capability, and the second entry must begin with "NOT POSSIBLE," corresponding to a state where the capability is completely absent. Additional degraded-states bins may be defined as the model dictates.

4.1.2.3.5 Structure Returning to the `System of Systems` indent level, the next keyword is `SOS Structure` for which the value is a dictionary of similar construction to the `Structure` dictionary within the SDF. One additional entry is made here: `Capability Edges`. There is no change to the treatment of administrative

or terminal nodes as compared to the SDF. `Edges` here only define connections between the terminal nodes belonging to the `sos` graph and terminal nodes of those `system` graphs that compose it. These edges are generally representative of those shown in the SOS sketch shown in figure A.12. The `Capability Edges` keyword corresponds to a dictionary of edge definitions that are required only to evaluate SOS capabilities. Generally, these connections begin and end at administrative nodes on separate `system` graphs within the `sos` graph. Refer to §3.2.4.3 for guidance on determining appropriate beginning and ending points for these edges.

4.1.2.3.6 Footer Like the SDF, SOSDF footer data is entirely optional, but the standard practice in NuSCAP identifies the `sos` model developer and any subsequent maintainers of the SDF. Other appropriate information may include contact information for these individuals.

4.1.2.4 Analytical Scenario Data File

Every analytical scenario must be defined by the analyst via the analytical scenario data file. The ScDF uses JSON syntax and the file extension "`.scdf.json`". An exemplar shell ScDF is provided in listing D.9. Some entries in the ScDF require a string to define directory and/or file paths on the computer system. Care should be taken to escape backslash characters (i.e., `\\` to represent a single backslash) such that Python appropriately parses the path string.

4.1.2.4.1 Header The `HEADER COMMENTS` keyword corresponds to a free-text entry where the scenario should be described in sufficient detail as to distinguish it quickly from others.

4.1.2.4.2 Prefix The `Prefix` field requires a string entry declaring the absolute system path to the analyst's preferred working directory. This path should correspond to the user's scenarios directory as shown in figure A.17 (e.g., `\\NuSCAP\\Users\\Dragon_5\\Scenarios`). Within this directory NuSCAP creates system working directories, MCNP working directories, and SNEC working directories to support its analysis.

4.1.2.4.3 Name The `Name` keyword requires a string to define the scenario. While unique names are helpful to distinguish scenarios and their output files, it need not be so. Special characters and spaces are not suggested here because the scenario name is used to make a working directory during the NuSCAP application run. If the user chooses to use special characters, they should be escaped in the Name string (e.g., `Ready\ \&\ Forward`).

4.1.2.4.4 MCNP Path The `MCNP path` keyword requires a string entry declaring the absolute system path to the directory containing the MCNP code executable file.

4.1.2.4.5 MCNP Data Path The `MCNP datapath` keyword requires a string entry declaring the absolute system path to the directory containing the MCNP code data libraries.

4.1.2.4.6 MCNP Threads The `MCNP threads` keyword requires an integer entry declaring the number of parallel processing threads the analyst wishes to use during the particle transport calculations in the `NuSCAP.env_tools.run_mcnp` method.

4.1.2.4.7 SNEC Path The `SNEC path` keyword requires a string entry declaring the absolute system path to the directory containing SNEC's `WebEffectsClasses.jar` file.

4.1.2.4.8 GIS and Weather Data The `GIS and Weather Data` keyword corresponds to a dictionary containing the following five keyword entries:

`GIS Reference Datum`	a string specifying the geodetic ellipsoid used in defining MGRS locations for the scenario (see §3.3.3);
`Ground Zero Location`	a string providing the MGRS grid to the AGZ location (spaces are permitted here, see §3.3.3);
`Ground Zero Elevation (MSL) [m]`	a numerical value (integer or floating point) defining the surface elevation in meters relative to MSL at the AGZ location (see §3.3.3);
`DTG`	an optional string entry declaring the date-time group of the detonation (spaces are permitted here) in `DD HHMMZ MON YYYY` format [16, p. 2-2] (see §3.3.3); and,
`Atmospheric Visibility [km]`	an integer or floating point number declaring the atmospheric visibility in kilometers (see §3.3.3).

4.1.2.4.9 Threat Weapon Data The dictionary corresponding to the `Threat Weapon Data` keyword defines a number of properties of the nuclear detonation being simulated along with parameters required to calculate the environments produced therefrom. The first several are short entries grouped together here under the heading of general weapon characteristics. Those that follow receive individual treatment with a more detailed discussion.

4.1.2.4.9.1 General Weapon Characteristics The first seven entries in the `Threat Weapon Data` dictionary are:

`Weapon Type` an optional input, this string describes the general type of nuclear weapon being simulated, suggested options are "fission," "boosted fission," and "thermonuclear;"

`Fission Fraction` for boosted fission or thermonuclear weapons, the fraction of total yield produced by nuclear fission processes;

`Yield [kt]` the total explosive energy (expressed in kilotons) released by the weapon (see §3.3.2);

`HOB [m]` the distance (expressed in meters) above the surface of the Earth at which the detonation occurs measured along a radial vector (see §3.3.2);

`HOB sigma [m]` one standard deviation (expressed in meters) with regard to the expected HOB as achieved on average by a specific weapon delivery system (see §3.3.2);

`CEP [m]` the radius (expressed in meters) of a circular area in which half of the ordnance delivered by a particular method is expected to land (see §3.3.2), and

`NPS` the number of neutron and photon particle histories to be run using the MCNP code (see §3.3.4).

4.1.2.4.9.2 Neutron Leakage Spectrum The next entry in the `Threat Weapon Data` dictionary is located at the `Neutron Leakage Spectrum` keyword. Within the corresponding dictionary structure, the analyst defines the neutron spectrum that emanates from the simulated nuclear detonation as a function of kinetic energy. This dictionary requires six keyword entries:

`neutron yield [mol/kt]` a floating point value specifying the quantity of neutrons produced by the simulated nuclear detonation in moles of neutrons per kiloton explosive yield;

`si option` an MCNP-specific entry specifying the treatment of energy values defined in the `energy bins [MeV]` list—"H" is the default value in NuSCAP, which specifies a monotonically increasing histogram bin upper boundary treatment [152, §5.8.2];

`energy bins [MeV]` a list of floating point numbers defining the upper boundary values of source neutron energy bins;

`sp option` an MCNP-specific entry specifying how probability values provided in the `probability [mol/MeV-kt]` list are treated—"D" is the default value in NuSCAP, corresponding to an "H" treatment of the energy bin structure [152, §5.8.3];

`probability` a list of floating point numbers, each of which describes the relative probability that a neutron within the corresponding energy bin is emitted; and,

`reference` an optional but highly encouraged entry whereby the analyst may declare the source of the preceding neutron leakage spectrum data.

4.1.2.4.9.3 Neutron Response Functions Stepping back out in the JSON structure, the next entry encountered is the `Neutron Response Functions` keyword. The corresponding dictionary provides flux-to-dose conversion factors for humans and equipment along with neutron fluence to 1 MeV-equivalent neutron fluence conversion factors. The `Human` keyword's associated dictionary provides data with which the `DE` and `DF` cards are created for the MCNP code. This dictionary requires four keyword entries:

`Energy [MeV]` a list of energy values corresponding to conversion coefficients provided in the `Conversion Factors` dictionary;

`Conversion Factor` a dictionary composed of two entries: `units`, that describes the units of the resulting quantities, and `values`, a list of coefficients by which tallies in each energy bin are multiplied to achieve the desired quantity;

`Quality Factor` an optional list of floating point values that declare the quality factor of a neutron at the corresponding energy; and,

`reference` an optional, but highly encouraged, entry declaring the source of the conversion factor data.

The `Equipment` keyword corresponds to a dictionary of two types of conversion factors. The first calculates a 1 MeV-equivalent neutron fluence, and the second calculates neutron dose to silicon-based electronic equipment. The subordinate `Fluence` dictionary is constructed similarly to the `Human` dose conversion factor dictionary. It contains three keyword entries:

`Energy [MeV]` a list of energy values corresponding to conversion coefficients provided in the `Conversion Factors` dictionary;

`Conversion Factor` a dictionary composed of two entries: `units`, which describes the units of the resulting quantities, and `values`, a list of coefficients by which tallies in each energy bin are multiplied to achieve the desired quantity; and,

`reference` an optional, but highly recommended, entry declaring the source of the conversion factor data.

After the `Fluence` dictionary, the `Dose` dictionary specifies tally multiplication values by which neutron fluence is converted to dose to silicon-based equipment. This dictionary takes three keyword entries:

`units` the dose of the converted quantity;

`values` the MCNP code-specific series of four numerical entries required for the `FM` card; and,

`reference` an optional but highly recommended entry declaring the source of the conversion factor data.

4.1.2.4.9.4 Photon Leakage Spectrum Next, the `Photon Leakage Spectrum` data is specified in the exact same way as the neutron leakage spectrum.

4.1.2.4.9.5 Photon Response Functions The `Photon Response Functions` dictionary reflects the same structure as the `Neutron Response Function` data, with only two exceptions. Those exceptions are: the absence of a flux-to-fluence conversion factor, and the absence of energy-dependent quality factors as an optional entry for the `Human` flux-to-dose response function dictionary.

4.1.2.4.10 Systems Data Returning to the outermost indention level in the ScDF, the next entry is the `Systems Data` dictionary. This data field contains a keyword entry for every system included in the analytical scenario. Only two entries are shown in listing D.9 for illustrative purposes. The keyword used must exactly match the system name provided in each system's SDF as well as that used in the SOSDF (e.g., `System_1_Name`). Each system name keyword corresponds to a dictionary holding a single keyword: `GIS Data`. Within the `GIS Data` dictionary, the analyst must input values for the following four keywords:

`Location (MGRS)` a string providing the MGRS grid to the system's location, specifically this grid is the location of the geometric center of the bottom face of the system (spaces are permitted here, §3.3.3);

`Elevation (MSL) [m]` a numerical value (integer or floating point) defining the surface elevation in meters relative to MSL at the system location (see §3.3.3);

`R95 [km]` the radius of a circle that circumscribes 95% of the system's constituent components, used only for widely dispersed "area" targets (zero for point targets) (see §3.3.3);

`Depth [m]` the depth below the surface at which the system exists if buried (see §3.3.3); and,

`Heading [grid deg]` the orientation of the front of the system with regard to true north (clockwise displacement is positive, see §3.3.3).

4.1.2.4.11 Transport Materials The `Transport Materials` dictionary defines all material types required for the neutral particle transport calculations carried out by the MCNP code in the scenario. In this initial development of NuSCAP, only three materials are required: the surface (earthen), the atmosphere (air), and a point detector "material" (silicon).

Three subordinate dictionaries under the keywords `Surface`, `Atmosphere`, `and Detector` define these materials. Within each of these dictionaries are four entries:

`Name` a unique string describing the material being specified;

`Density [g/cm^3]` the mass density of the bulk material;

`Composition` a dictionary with keyword entries for each the ZAID (e.g., `6012` for the isotope carbon-12) of each substance present in the material and a corresponding value given in atom fraction or mass fraction describing the portion of the whole composed of each ZAID; and,

`Notes` an optional, but highly encouraged entry, that may be used to declare the source of the material composition data or other pertinent information.

4.1.2.4.12 Footer In the same style as the SDF and SOSDF formats, this field is particularly useful for identifying the ScDF developer(s) and maintainer(s).

4.2 User Guide

This section provides a general introduction to the execution of the NuSCAP application, interpretation of results, and discussion regarding common warnings, errors, and troubleshooting.

4.2.1 Running NuSCAP

After the analyst produces the requisite data files, the NuSCAP application is capable of performing a SOSVA. To do so, the analyst opens a command line interface terminal and navigates to the NuSCAP home

directory (see fig. A.16). At the command line, the user enters the following command:

```
~/NuSCAP>   python NuSCAP.py --sos <sos.name> --sosdf <path to SOSDF> --scdf <path to ScDF>
```

From here, the NuSCAP application runs without intervention until the `sos` graph is displayed by the `sos.show_sos_graph` method. The analyst should take this opportunity to review the `sos` graph for any mistakes or errors. If the analyst notes an error in the `sos` graph construction, entering the command `Ctrl+C` in the terminal window will end the run and allow alterations to be performed as required. Closing the graph display window causes the NuSCAP run to continue. Warnings and errors will print to the screen as necessary.

In general, the application runs quickly—typical timing is discussed in §5.3. The prevailing consumer of computational power and time is the MCNP code. The time required is a function of the number of particle histories and the number of parallel threads specified in the ScDF, the computer's processor speed, and the extents and complexity of the SOS model produced for MCNP by the `env_tools._build_mcnp_input` method.

At the conclusion of a successful run, "`The NuSCAP™ analysis is complete!`" prints to the screen.

4.2.2 NuSCAP Results

NuSCAP results are presented in two forms: a PDF image of the `sos` graph produced following evaluation of the `sos` graph's nodes, the `sos` functionality, and its capabilities; and, as NuSCAP report JSON files. These products are all written to disk within the scenario working directory. An example of a post-analysis graph produced during unit testing of the application is shown in figure A.18. This image provides the analyst with a visual reference regarding the extent of dysfunction and which nodes are affected.

Examples of NuSCAP report JSON files produced during unit testing of the application are provided in listings 4.1 and 4.2.

When reviewing a `system` report file (listing 4.1), the analyst first encounters header comments identifying the system and scenario for which the analysis is conducted. The date and time of the report are also provided. Next, a dictionary of the `system`'s analyzed capabilities is presented. Within the `system` dictionary, a written statement of the system's functionality type (i.e., "functional" or "dysfunctional") appears followed by a dictionary for each analyzed capability. Each capability name is the keyword to yet another dictionary that states the maximum residual capability followed by a dictionary of all possible bins and the Boolean condition thereof. The final entries of the `system` report are individual dictionaries representing each `element` of the `system`. Within each of these dictionaries are two entries: the `element`'s functionality type and a

`Cause(s) of Dysfunction` list. The `Cause(s) of Dysfunction` list is empty for a functional `element`, but for dysfunctional `elements`, the name of each dysfunction threshold with its value exceeded during the analysis is listed individually (see listing 4.1, `VHF Antenna 1`).

Listing 4.1: Example system report (System 1.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of System 1 and its subordinate elements during Degraded_Scenario_(Bin_3).  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "27 1722 June 2023",
    "System 1": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "R/T Short-Range Communications w/ System 3": {
                "Maximum Capability": "Cannot R/T short-range data communications",
                "Capability States": {
                    "R/T Data via Cable and Control Panel": false,
                    "NOT POSSIBLE": true,
                    "R/T Data via Control Panel 3 ONLY": false
                }
            },
            "R/T Communications w/ System 5.1": {
                "Maximum Capability": "Cannot communicate w/ System 5.1",
                "Capability States": {
                    "Communicate via VHF Radio and Fiber Optic Cable": false,
                    "NOT POSSIBLE": true,
                    "Communicate via VHF Radio ONLY": false,
                    "Communicate via Fiber Optic Cable ONLY": false
                }
            },
            "R/T Communications w/ System 5.2": {
                "Maximum Capability": "Cannot communicate w/ System 5.2",
                "Capability States": {
                    "Communicate via VHF Radio and Fiber Optic Cable": false,
                    "NOT POSSIBLE": true,
                    "Communicate via VHF Radio ONLY": false,
                    "Communicate via Fiber Optic Cable ONLY": false
                }
            },
            "R/T Short-Range Communications w/ System 2": {
                "Maximum Capability": "Cannot R/T short-range data communications",
                "Capability States": {
                    "R/T Data via Cable": false,
                    "NOT POSSIBLE": true
                }
            }
        },
        "System 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Subsystem A1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Subsystem B1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Subsystem D1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Subsystem E1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Soldier 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Soldier 2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Soldier 3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Control Panel": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "RWCIU 1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Data Cable 1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Weapon Control Computer": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Antenna 1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure",
                "windspeed"
            ]
        },
        "Fiber Optic Modem 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Fiber Optic Cable 1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Cable 1.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure",
                "windspeed"
            ]
        },
        "AA_1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "BB_1_1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "BB_1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "DD_1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EE_1_2a": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EE_1_2b": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EE_1_1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EE_1_2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EE_1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "X_1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "XX_1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
```

```
}
```

The `sos` report file (listing 4.2) format mirrors the `system` report but provides data only down to the system level. The header data and report date and time are retained. A `sos` dictionary appears next with the `sos` name as the keyword (e.g., `Degraded SOS`). Within the dictionary is the `sos` functionality type and a `Residual Capabilities` dictionary. The `Residual Capabilities` dictionary provides subordinate dictionaries for each evaluated capability. Like in the `system` report, these individual capability dictionaries report the maximum residual capability followed by yet another dictionary of all possible bins with corresponding Boolean conditions. The final entries of the `sos` report are individual dictionaries representing each `system` within the `sos`. Within each of these dictionaries are two entries: the `system`'s functionality type and a `Cause(s) of Dysfunction` list. The `Cause(s) of Dysfunction` list is empty for a functional `system`, but for dysfunctional `systems`, the name of each dysfunction threshold with its value exceeded during the analysis is listed individually. Of note, the causes of dysfunction listed apply to the dysfunction thresholds specified for the `element` representing the `system` as a whole, not all of the `elements` therein. See §4.1.2.2.5.1 for additional discussion.

Listing 4.2: Example SOS report (SOS.out.json)

```
{
    "HEADER COMMENTS": "This file reports the functionality and residual capabilities of Degraded SOS
    during Degraded_Scenario_(Bin_3).
                        Causes of dysfunction for constitutent systems are also reported.",
    "DTG of Report": "27 1722 June 2023",
    "Degraded SOS": {
        "SOS Functionality Type": "functional",
        "Residual Capabilities": {
            "Power Core Systems": {
                "Maximum Capability": "Power System 1 and 3 ONLY",
                "Capability States": {
                    "Power Systems 1, 2 and 3": false,
                    "NOT POSSIBLE": false,
                    "Power System 1 and 3 ONLY": true,
                    "Power System 2 and 3 ONLY": false
                }
            },
            "Control/Monitor Power Generation": {
                "Maximum Capability": "Control Power Generation via cable and control panel",
                "Capability States": {
                    "Control/Monitor via Cable and Control Panel": true,
                    "NOT POSSIBLE": false,
                    "Control via Control Panel ONLY": false
                }
            },
            "Control/Monitor System 2": {
                "Maximum Capability": "Cannot control System 2",
                "Capability States": {
```

```
                    "Control/Monitor via Cable": false,
                    "NOT POSSIBLE": true
                }
            },
            "Control/Monitor Weapon System 5.1": {
                "Maximum Capability": "Control/monitor System 5.1 via OF ONLY",
                "Capability States": {
                    "Control/Monitor via Optical Fiber or VHF Radio": false,
                    "NOT POSSIBLE": false,
                    "Control/Monitor via VHF Radio ONLY": false,
                    "Control/Monitor via Optical Fiber ONLY": true
                }
            },
            "Control/Monitor Weapon System 5.2": {
                "Maximum Capability": "Cannot control/monitor System 5.2",
                "Capability States": {
                    "Control/Monitor via Optical Fiber or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Control/Monitor via VHF Radio ONLY": false,
                    "Control/Monitor via Optical Fiber ONLY": false
                }
            }
        },
        "System 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "System 2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "System 3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "System 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "System 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```


While evaluating the results of any NuSCAP analysis, the user should consult the MCNP code output files located in the scenario's MCNP working directory. Specific attention should be given to the statistical reports for each tally. Any tallies that exhibit high variance-of-variance or variance values warrant investigation and may indicate the need for increasing the number of particle histories calculated during each MCNP code run or more advanced variance reduction methods. Such methods are given extensive treatment in [152, §2.7].

4.2.3 Warnings, Errors, and Troubleshooting

It is possible for a NuSCAP analyst to experience unforeseen issues during operation of the NuSCAP application. During the course of application development and unit testing, conditional error and warning statements were implemented to help avoid some of the most likely issues one may encounter. Various Python `KeyError`, `TypeError`, and `ValueError` statements exist to prevent the analyst from experiencing unannounced errors caused by providing improperly formatted input data. These error statements are defined in the documentation string of each NuSCAP package provided in appendix D.

Likewise, a few warning statements are provided throughout the application. These are most commonly used to announce to the analyst that a nuclear weapon environment calculation was attempted outside the bounds of the associated computational model (e.g., PDCALC or SNEC) and that a valid numerical value was not provided. Thus, the `element(s)` in question are not evaluated against that particular nuclear weapon environment.

While these warning and error messages are designed to assist the analyst in successfully executing a NuSCAP analysis, it is possible that identification of so-called "undocumented features" [167] (i.e., bugs) may arise. Copious comments and documentation strings are provided throughout the NuSCAP modules to assist the analyst with troubleshooting and making any modifications required to remedy such undocumented features.

Chapter 5

Case Study Results

Mr. President, I'm not saying we wouldn't get our hair mussed...

George C. Scott as General Buck Turgidson,
in *Dr. Strangelove or: How I Learned to Stop Worrying and Love the Bomb*

As proof of the NuSCAP methods and the execution thereof by the NuSCAP Python application, a case study was undertaken to demonstrate the first recorded nuclear SOSVA on a representative, conventional, military target SOS. This chapter covers case study parameters including definition of nine systems, a SOS, and three analytical scenarios. Any improvements upon or deviations from the methods and procedures discussed in chapters 3 and 4 are disclosed. Results of the case study are discussed with full output reports provided in appendix F.4.

5.1 System of System Definition

A model of a representative, conventional, US Army SOS was developed according to the processes discussed in chapter 3. The SOS in question consists of a command and control system, a target sensor (detection and classification) system, an electric power plant system, and six individual weapon systems. Each weapon system is identical in form and function. A lengthy discussion of the SOSDF is not necessary here, but for completeness it is given in appendix F.3.1. Likewise, the supporting, subordinate SDFs are provided in appendix F.3.2. The full `sos` graph and the subordinate individual `system` graphs are provided in appendices F.1 and F.2, respectively. Because of the identical nature of the six constituent weapon systems, only one such graph is provided for reference.

During the development of the system and SOS models, it became evident that actual dysfunction thresholds of interest are not readily available. Hence, mean dysfunction threshold values were chosen based on reasonable expected values and agreed upon by the author and select members of the research committee. The values are documented in table B.9 by `element` subtype. The subtype field was added at the onset of the case study to permit batch assignment of dysfunction thresholds according to categories of equipment included in the model. It need not be a standard entry in the SDF since the NuSCAP application itself does not access these values. To give a sense of realism to these values, the mean value was multiplied by a coefficient chosen from a truncated, randomly sampled normal distribution with a mean of unity and a standard deviation of 0.25. No values equal to or less than zero were accepted. The process was automated using a short utility script provided in appendix D.3. Fuzzing the dysfunction threshold values in this manner also accounts for the stochastic nature of nuclear weapon effects along with manufacturing or maintenance inconsistencies between individual platforms in the case of the six weapon systems modeled in this study.

5.2 Scenario Definitions

Three scenarios were investigated as part of this case study. The scenarios differ only in the AGZ location of the simulated nuclear weapon detonation relative to the SOS formation. The scenarios are named Volunteer Plasma (directly overhead of the target sensor system), Volunteer Tan (∼1.5 km from the target sensor system), and Volunteer Sunrise (∼3.9 km from the target sensor system). The ScDFs for each are included in appendix F.3.3.

The scenarios have many factors in common. The location of each is in the vicinity of the Trinity test site on White Sands Missile Range, New Mexico. A clear day with atmospheric visibility of 16 km is specified with dry air (near sea level) [162, table 4] and average US earth [162, table 116] serving as the radiation transport media for the atmosphere and ground surface, respectively. The notional threat weapon is a 10.0 kt fission device detonated at a FFHOB of 139 m above the ground. The neutron and photon leakage spectra specified are those published by Holmes and White [71] corresponding to the Fat Man bomb dropped on Nagasaki, Japan on 9 August 1945. Flux-to-dose and 1 MeV-equivalent neutron conversion factors are standard throughout.

The SOS in all three scenarios is deployed per standard US Army doctrine with the command and control, power generation, and target sensor systems in close proximity of one another protected by a lazy-W formation of weapon systems almost a kilometer to their front arrayed along an east-west line. The easternmost and westernmost weapon systems (weapon systems 5.1 and 5.6) are oriented outward in their respective direction

at 20° off north. The two weapon systems next inboard of these (weapon systems 5.2 and 5.5) are oriented on headings 10° off north in their respective direction. The remaining two weapon systems are oriented toward true north. The approximate deployment formation of the SOS is shown in figures A.19 and A.20.

Figures A.21–A.23 show the three scenario arrangements with the detonation point depicted relative to the deployed SOS. The variation in AGZ locations demonstrates NuSCAP's ability to provide quantifiable, degraded states, capabilities-based SOSVA results in three distinct damage regimes. Volunteer Plasma is expected to result in complete loss of capability in the three nearest systems with significant degradation and loss of most capabilities in the weapon systems. Volunteer Tan is expected to produce some intermediate level of damage resulting in significant loss of capabilities in nearby weapon systems while distant weapon systems, the command and control system, the electric power plant, and the target sensor system were expected to retain some if not all capabilities in a degraded state. Volunteer Sunrise is expected to cause only minimal damage to some of the weapon systems resulting in loss of some capabilities with degraded capabilities to fire ordnance in some.

5.3 Analysis Execution

The case study NuSCAP analyses were performed on a Dell™[1] Precision™ 7550 mobile workstation running the Microsoft® Windows® 10 Enterprise 64-bit operating system. The workstation is powered by an Intel® Xeon® W-10855M processor with six cores and twelve available parallel processing threads rated at 2.80 GHz processing speed. Installed memory during the NuSCAP simulations was 128 GB.

As expected, the analyses were completed quickly but not so speedily as to be considered a "fast running tool" by most nuclear weapon effects expert standards. The greatest computational time investment is execution of MCNP6.2 calculations. A few trials were performed to optimize the balance between speed of completion and attaining workable (e.g., ∼50% on average) tally statistics at the conclusion of the MCNP code calculations. This arbitrary threshold for tally statistics likely seems out of place to the Monte Carlo practitioner. Much lower statistical variance is desired, but on a mobile workstation with few variance reduction measures, the ∼50% metric is taken as sufficient for proof-of-concept. With eight parallel processing threads specified, a NuSCAP simulation including a MCNP6.2 calculation with 100,000 particle histories in both neutron and photon calculations (200,000 particle histories, total) successfully concluded in about 17 minutes. The three case study analysis simulations (each calculating 500,000 particle histories per file, 1,000,000 histories total) completed in an average of 83 minutes.

[1] Dell Technologies, Dell, and other trademarks are trademarks of Dell Inc. or its subsidiaries.

It is noted that the `logging` Python package used throughout the NuSCAP application prints an inordinate amount of detail to the screen during a typical NuSCAP run. This excess data confounds the analyst's ability to observe pertinent error and warning messages produced by the NuSCAP application, PDCALC, SNEC, and the MCNP code. Much of the extraneous information falls under the `logging.DEBUG` category and seems to correspond to the sub-optimal method of graph display. Refinement of the `logging` settings throughout the NuSCAP application is warranted. This refinement will reduce the volume of output to the user's terminal screen.

Also noted during the first trial run of a full scenario is the truncated availability of VNTKs in PDCALC. Although the associated PDWIN GUI allows the user to define a wide variety of VNTKs for which it will produce automated outputs, the Python-compatible wrapper only permits the investigation of a subset of these. Specifically, an error message was produced when attempting to evaluate personnel with a VNTK of 50I1. The error message reads:

```
ERROR CODE = 8
INVALID PERSONNEL VNTK
PERSONNEL VNTKS MUST BE 99IA TO 99IU, 2I0 TO 22I0, OR
30I1 TO 36I5, 40I1 TO 45I5, 50I4, 50I5, OR 51I0
```

This error required the analyst to change the personnel VNTK value to 50I4. The 50I4 VNTK corresponds to the 50% probability of fatality threshold for personnel exposed to a nuclear detonation while shielded from the weapon's thermal pulse. This VNTK is appropriate for the case study scenarios where all three personnel in the model would be actively performing duties while thermally shielded by the command and control system's box truck-like personnel and equipment shelter.

Initial MCNP6.2 codes failed to run because the `message` card length in both input decks exceeded the 128 column limit. This error was not immediately observed because the text was effectively hidden in the midst of the `logging.DEBUG` printout. Once the error was identified, the author corrected the directory and file naming conventions to meet the 128 character limit. The cause of the excessive character count is the deeply nested location of the author's NuSCAP user directory on his system. A user who installs NuSCAP at a higher-level directory should not experience this issue.

5.4 Analytical Scenario Results

The results for all three analytical scenarios considered during the case study are provided in appendix F.4 in the form of SOS- and system-level report files produced by NuSCAP. NuSCAP-generated SOS-level graphs

are also provided for completeness. Little utility is observed when viewing either type of graph in standard print form on US letter-sized (8.5 in $\times$ 11 in) paper. Ideally, the user should view these outputs on a large digital display with high resolution. The Python matplotlib display window and standard PDF viewers enable the user to pan and zoom on the images permitting visual evaluation of the graphics.

In the following sections, a synopsis of the results from each scenario is provided with discussion of residual capabilities at the SOS and system levels.

5.4.1 Volunteer Plasma

The Volunteer Plasma scenario resulted in complete loss of capability across the entire SOS, as expected. Blast environments (i.e., static overpressure, dynamic pressure, and/or windspeed) were the primary causes of dysfunction at the system level. The absence of dysfunction due to thermal fluence or ionizing radiation environments is primarily due to the classification of the overarching system nodes as either "mechanical" or "weapon" subtypes. These subtypes have no associated thresholds for thermal or ionizing radiation environments.

The command and control, electric power plant, and target sensor systems suffered system-wide dysfunction and loss of all capabilities because of multiple environment threshold excesses. Conversely, all six weapon systems lost all capabilities simply due to overturn caused by the blast wave interaction with the systems. This result is especially noteworthy because the blast overturn threshold specified as a windspeed environment for the weapon systems. This is one of two dysfunction threshold data points found in the literature for any of the systems, subsystems, or components involved in the case study. Similarly, a windspeed failure threshold value associated with communications antennae (see fig. A.15) was applied for all antennae in the case study. All weapon systems, the target sensor system, and the command and control system lost capabilities requiring their antennae due to excessive windspeeds in this scenario.

5.4.2 Volunteer Tan

The Volunteer Tan scenario resulted in a dysfunctional SOS. While expected to sustain some damage, the analyst projected that at least some degraded residual capability would remain at the SOS level. This expectation was proven incorrect by the loss of all antennae on the target sensor system because of excessively strong winds even at a distance of over 1,500 m. Likewise, all six weapon systems were overturned due to high winds and suffered a myriad of other dysfunctional elements leading to various levels of degraded capabilities. A summary of dysfunctional `element` count and exceeded dysfunction thresholds for the six weapon systems

is provided in table B.10 along with the approximate ground range of the system from AGZ and a breakdown of dysfunctional `element` count by cause of dysfunction.

By inspecting these data in conjunction with the full `system` reports, the analyst notes that excessively high winds affects the same three elements of all six weapon systems. These elements: the GPS antenna, the VHF radio antenna, and the `element` representing the full system (i.e., the body of the system overturns because of high winds) fail in each case. Given that this particular failure mechanism is one for which reliable threshold data exists, these results (along with the loss of all three antennae on the target sensor system) lead one to believe that these critical elements of the SOS should be reinforced against wind damage if the SOS is intended to serve in hostile environments where a nuclear weapon threat exists. It is such analysis capabilities that speak to NuSCAP's applicability to the JCIDS acquisition processes and real-world operations. Knowing this paradigm exists, an operational commander may consider reinforcing the weapon systems with some sort of static anchor when in a defensive posture where rapid redeployment is not likely or necessary.

Conversely, the command and control and electric power plant systems retained all capabilities in this scenario. The command and control station suffered degradation of its ability to control the six weapon stations upon loss of its VHF radio antenna because of high winds. The electric power plant system retained all capabilities in the highest possible state, suffering no dysfunctional elements.

5.4.3 Volunteer Sunrise

The results of the Volunteer Sunrise scenario show that the SOS remains functional after exposure to the specified detonation with all systems situated at ground ranges in excess of 2.8 km. In this instance, NuSCAP reports only two dysfunctional `elements` among the 455 that compose the SOS model. The dysfunctional elements in this case are also two VHF radio antennae—elements of Weapon System 4 and Weapon System 6. This fact underpins the evidence shown in the Volunteer Tan scenario indicating that any CBRN mission-critical systems that rely on rigid antenna masts warrant further scrutiny and possible upgrade to gain resiliency against this environment. Nevertheless, these weapon systems both remained functional because of redundant communication systems in the form of fiber optic data transmission capabilities.

Because of the redundant communication capabilities built into the command and control system and the weapon systems, the SOS retains all capabilities. Only the capabilities to fire ordnance from the two affected weapon systems are degraded. These facts together with the results of Volunteer Tan indicate that a 10 kt detonation must occur within approximately two kilometers of the SOS formation to produce significant capability losses.

5.5 Summary

The case study undertaken in this work demonstrates the ability of the NuSCAP method and application to perform capabilities-based, SOSVA of a military target in nuclear weapon environments. Exposure of a conventional, representative US Army SOS to three damage regimes produced losses of capability at the system- and SOS-levels commensurate with what was expected. For this particular SOS model, it is evident that blast damage (particularly that to weapon systems and communications antennae) is the predominant cause of elemental dysfunction and associated degradation of capabilities. Results of such studies provide insight for operational commanders who require mission planning and post-strike recovery and reconstitution efforts. Likewise, future acquisition programs and force developers may employ these results to refine JCIDS requirements and improve future SOS resiliency to blast environments.

Further details regarding certain operationally relevant application of results gleaned from this work are available in a limited-distribution document. See appendix G for details.

Chapter 6

Concluding Remarks

Obsolete weapons do not deter.

MARGARET THATCHER

This chapter provides concluding remarks regarding the development and demonstration of the NuSCAP method and application. Attention is also given to challenges and lessons learned throughout the process. Suggestions for future application and extension of NuSCAP are provided.

6.1 Accomplishments

This work documents the development and proof-of-concept demonstration of NuSCAP—the first capabilities-based, degraded states, system-of-systems vulnerability analysis method designed specifically to evaluate systems of systems exposed to nuclear weapon environments. The NuSCAP method combines proven, conventional SOSVA processes with graph theory analysis methods, industry standard nuclear weapon environment calculators, and the extensively benchmarked MCNP radiation particle transport code. A Python computer application permits the fully automated analysis of a user-defined SOS that includes detailed models of each individual system to whatever practical degree of detail is desired.

The viability of this method has been demonstrated by way of three case scenarios that evaluate a deployed, representative US Army SOS exposed to nuclear weapon environments of varying intensity. The results of the case studies show that the integration of established SOSVA protocols and nuclear weapon effects tools by the NuSCAP application provides the DoD with a capability to facilitate increased understanding of nuclear weapon effects on a modern, networked fighting force at the SOS level. This understanding surpasses

traditional pseudo-quantitative loss-of-function metrics by quantifying the maximum residual capability states and the functional states of the SOS and its subordinate systems, subsystems, and components. Furthermore, these results enable identification of the most consequential nuclear weapon environments (i.e., those causing the greatest proportion of dysfunction in the SOS) and permit force developers, planners, and commanders to devise tactics, techniques, and procedures to achieve increased systemic resiliency in current and future SOS.

The existence of NuSCAP as a method and computer application underpins three US Army CNI strategic objectives [39, p. 1–2], the Army's abilities to:

- dominate operations in and through a nuclear environment;
- exploit its resiliency advantage; and
- prepare for post-strike recovery.

NuSCAP accomplishes this by:

- signifying the Army's support to the US strategic deterrent as a potential force-wide risk-mitigation tool;
- enabling assessment of current Army manning, force design, and force employment on a nuclear battlefield;
- providing a platform with which soldiers and leaders across the force may be educated about the practical battlefield effects of nuclear weapon employment by the US or our adversaries;
- supporting analysis of current and future strategically important SOSs against nuclear weapon environments to drive future materiel MBT&E and acquisitions programs; and,
- creating a new capability that enables investigation of modern, deployed, conventional SOS vulnerabilities to nuclear weapon effects.

NuSCAP ultimately provides the DoD with a tool by which it is possible to understand vulnerabilities of strategic conventional SOS to nuclear weapon effects from friendly or adversarial use, develop DOTMLPF-P strategies to address those vulnerabilities, and assess necessary repair and reconstitution measures in the case of actual nuclear weapon use on the battlefield.

6.2 Challenges to NuSCAP Analyses

Although NuSCAP shows promise as a multi-mission tool supporting Army CNI, a number of challenges to optimizing the NuSCAP method, application, and results arose throughout the development and case study processes. Several of these challenges persist and limit NuSCAP's immediate applicability. These issues and proposed solutions are presented here.

6.2.1 Nuclear Weapon Environment Dysfunction Thresholds Data

Chief among the challenges to producing an accurate NuSCAP analysis model is the current unavailability of dysfunction thresholds corresponding to each nuclear weapon environment for a given component, subsystem, or system. In the case study presented as part of this work, stated limits for nuclear weapon environments included in NuSCAP were found for only two types of elements (i.e., a communications antenna and a weapon system). Furthermore, those two element types have dysfunction threshold values for only one of the nuclear weapon environments considered: windspeed.

Because of this paradigm, NuSCAP analyses are presently relegated to proof-of-concept status. Without individual component, subsystem, and system testing in nuclear weapon environment simulators, analyses such as those performed by NuSCAP will deliver limited results based in reality. This conclusion suggests that the DoD should undertake increasingly robust testing campaigns for critical parts and pieces of strategically important SOSs. Specifically, as the Joint Force becomes ever more reliant upon digital electronics to fight and win the Nation's wars, large-scale testing of digital electronics in the as-built configuration within their parent systems in ionizing radiation and shock environments at magnitudes commensurate with nuclear weapons is indicated. While DTRA and others presently conduct such testing on a limited basis, the volume and pace of testing requires significant acceleration.

Accelerating parts testing is not a small undertaking. A great deal of capital investment in materiel, facilities, and instrumentation is likely required to accomplish this feat. However, without such data, NuSCAP and other such vulnerability M&S efforts will suffer from unacceptable and unquantifiable levels of uncertainty. Given the current international security environment, this lack of data also constitutes acceptance of risk at the strategic level. Absent the ability to rapidly expand the nuclear weapon environments testing enterprise, accelerating M&S efforts for critical elements of strategically important SOSs seems a tractable first step. Application of DoD and DOE supercomputer facilities to blast and thermal multiphysics finite element analysis (FEA) studies of such SOSs and their critical constituents is one such option.

6.2.2 System and SOS Data Availability

At the outset of the work, the author desired to achieve high-fidelity particle transport results within the NuSCAP application according to the methods demonstrated by Spencer and Goorley [66, 67, 117, 121, 122]. To facilitate this desire, the sponsors and the author sought out CAD models and associated material specifications for the four system types included in the NuSCAP case study. After expending a great deal of time and effort, contacting the SOS program executive offices (PEO), the associated US Army centers of excellence, several operational units that employ the SOS, the prime contractor, and multiple subcontractors, it became clear that such CAD models and associated data are not readily available. In fact, this investigation led to the conclusion that because of contractual obligations written into the procurement documents, the CAD models, material specifications, and other such technical data are the province of prime and sub-contractors. The DoD, at least in this instance, does not retain primary control of or access to these data. The logical assumption then is that any request for NuSCAP (or any other) analysis requiring high-confidence particle transport results will require extending or rewriting present contracts for the SOS in question.

Therefore, it is suggested that acquisition of future systems that require or may require nuclear survivability specify the following in JCIDS documentation (or such vehicles as supersede JCIDS documents):

- The DoD (or the individual service) retains full rights of access to as-built CAD models of each system.
- Components and subsystems of a given size and/or proximity to critical electronic components or personnel are accompanied by bulk material analysis data including average mass density and elemental mass fraction.
- Such data is stored in a centralized repository of CBRN survivability data accessible to DTRA, USANCA, and the PEO(s) at an appropriate level of classification.
- All contractors involved in the acquisition, maintenance, and life cycle upgrade of such systems agree to provide this data for all major upgrades (e.g., Abrams tank system enhancement packages) in perpetuity.

6.2.3 Analysis Team Composition

Another challenge to NuSCAP analysts is gaining a practical, operational understanding of the SOS to be analyzed. The formation of a diverse and experienced analysis team for each unique SOS is appropriate. While the doctrinal, technical, and organizational documentation discussed in §3.2 provide academic insight to the form and function of the SOS and its many parts, an analyst without practical experience is left

wanting. The following discussion provides the minimum requirements for composing a proper analysis team based on observations during this work.

A much-improved situation centers on a team of experts in the various systems and the actual employment thereof in combat or field operations. This team should include a tactician or strategist who employs the SOS (e.g., a commander), technicians with ample experience operating the systems (e.g., senior noncommissioned officers or warrant officers), system maintainers, and engineers and builders who design and assemble the systems. Also important is the presence of one or more team member(s) with experience in nuclear weapon effects analysis, radiation particle transport simulations, and system criticality analysis. Personnel with FEA and computational fluid dynamics (CFD) expertise provide added value.

While this team may seem overly robust at first glance, the complexity of problem(s) addressed by a nuclear SOSVA demands such breadth and depth of expertise to produce accurate and useful results. Some decisions made in the production of case study models for this work were informed by experience and intuition alone beyond the scope of the aforementioned documentation. These assumptions bring with them increased uncertainty and the possibility of outright error when left unchecked. While the values used in this work represent the best effort of the author given limited available datasets, the assembly of a team of experts in the various aspects of design, assembly, implementation, and analyses is suggested to reduce this uncertainty and eliminate error. The influence of a team of such experts is supremely important to filling potential knowledge gaps in this area and refining the resulting assumptions.

Furthermore, access to the much-storied, proverbial, "digital twin" models of the systems that compose the SOS in question would greatly benefit this effort. An as-built digital model provided by the system contractor(s) prevents an analyst (or analysis team) from reinventing the system based on a perhaps-tenuous understanding of the doctrinal and technical documentation available. This ensures parity between the computational model and the SOS that may experience nuclear weapon effects on the battlefield.

6.3 Future Work

With the development of most evolutionary technology comes the desire to further its capabilities and range of application. Such is true in this work. The sections that follow discuss a number of desirable additions to NuSCAP in suggested order of priority.

6.3.1 Statistical Approach to Dysfunction

At present, NuSCAP operates on binary and Boolean logic. That is, all elements are treated as either fully functional or fully dysfunctional and all dysfunction thresholds are represented by an artificially-fuzzed single value. It is desirable to employ the results of the testing campaign suggested in §6.2.1 along with associated M&S efforts to quantify dysfunction thresholds in the form of probability density functions (PDF) that may then be randomly sampled and employed in NuSCAP analyses. This addition would require alteration of present methods and development of additional methods in the `env_tools`, `system`, and `sos` packages. These changes would require methods to define and sample the PDF for each `element` type and assign the sampled value to `element` objects within the model. In doing so, the Monte Carlo method may be applied to any given scenario. By running many iterations of the same scenario with randomly sampled dysfunction thresholds for each element of the model, a set of expectation values for the status of the SOS, each system, and the capabilities thereof may be constructed. Such an approach allows the analyst to account for the stochastic nature of component behavior when exposed to environments that may render them dysfunctional.

6.3.2 Optimize and Expand Radiation Particle Transport Models

Directly related to the discussion in §6.2.2 is the desire to include advanced unstructured mesh geometries in the MCNP code calculations within NuSCAP. With the availability of 3-D CAD models of each system, the analyst may create UM representations of important geometries and materials that provide radiation shielding and protection to various elements of the SOS. By taking the approach presented in work by Spencer and Goorley [66, 67, 117, 121, 122], the overly conservative free-air, point detector tallies currently used in NuSCAP are replaced with volumetric cell fluence and dose tallies. These tallies may more accurately represent the actual doses, dose rates, and fluences experienced by model elements by including the RPFs afforded by external components of the systems. Similarly, application of these methods and those presented by McClanahan, et al. [46, 99, 100] would enable the addition of terrain effects, neutron activation, and atmospheric pollution.

Particle transport calculations within NuSCAP would also benefit from the skilled application of variance reduction measures throughout the model. Presently, the use of point detector tallies is the only variance reduction technique included in the MCNP code input files created by NuSCAP. This leads to widely varying tally statistical uncertainty and variance-of-variance values. Because of the relatively large model space (cubic kilometers), tallies far from the source suffer from high statistical uncertainty while those closer to the source fair much better. Including weight window generation and/or DXTRAN spheres may be appropriate (once

more-complex system geometries become available) to reduce statistical uncertainty and variance-of-variance values while also optimizing computational resource allocation.

6.3.3 Addition of Other Nuclear Weapon Environments and Use Cases

The threat of EMP damage to a deployed SOS is not presently addressed by NuSCAP. The addition of a NuSCAP method in the `env_tools` package to interface with EMREP, SREMPTAPS [36, chapter 7], and/or HEMPTAPS [36, chapter 7] should be considered.

While NuSCAP is designed to assess military SOSs vulnerability to nuclear weapon environments, it is flexible and extensible in nature. These qualities enable it to model any SOS, and as Reardon [170] points out, the EMP threat also concerns civilian infrastructure. Exploring the application of NuSCAP to effects of nuclear detonations on civilian infrastructure is a possible area of future research.

Furthermore, exploring the development of the NuSCAP application to support interfacing with dynamic, turn-based combat simulations is warranted. In this way, NuSCAP capabilities may be more easily exploited to support wargaming efforts and application of the missions and means framework (MFF) as discussed in [10, 40–43, 148].

Some also suggest consideration of this type of analysis for evaluation of space vehicles, habitats, and astronauts themselves in preparation for future interplanetary expeditions to Mars [171].

6.3.4 Resilience in Nuclear and Kinetic Environments

Finally, combination of NuSCAP with its namesake SCAP method could provide the DoD with a tool capable of evaluating SOS resiliency in nuclear *and* kinetic environments (RINKE). This multi-environment tool would enable development of a standardized evaluation method for CNI wargaming, planning, targeting, and consequence-of-execution analyses. Given the propensity of US adversaries to pursue non-strategic nuclear weapons, it is possible that the need to assess synergistic nuclear and conventional effects may arise. Investigation into this type of M&S effort should be explored.

6.4 A Final Word

The field of nuclear weapon effects studies began with a letter [172] to President F. D. Roosevelt wherein Einstein proposed: “A single bomb of this type [nuclear], carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory.” Since then, the United States has invested untold time and fortune into understanding the environments and effects produced by

these awesome weapons. NuSCAP embodies an evolutionary, yet consequential, advancement in this field. If pursued in a steadfast manner, application of this method will constrain studies of this type no longer to semi-quantitative, fractional statements regarding equipment loss, personnel loss, or loss of function. Now, quantifiable declaration of an integrated, complex SOS's various capabilities within a discrete degraded-states binning system is possible.

The work presented here constitutes the first documented SOSVA process capable of quantifying the degradation of SOS capabilities because of exposure to nuclear weapon environments. Although significant work remains to enable the production of results that accurately reflect reality, the NuSCAP method and application have been proven as viable means of conducting nuclear SOSVA.

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Appendices

Appendix A

Figures

A.1 Chapter 1

Chapter 1 contains no figures.

A.2 Chapter 2

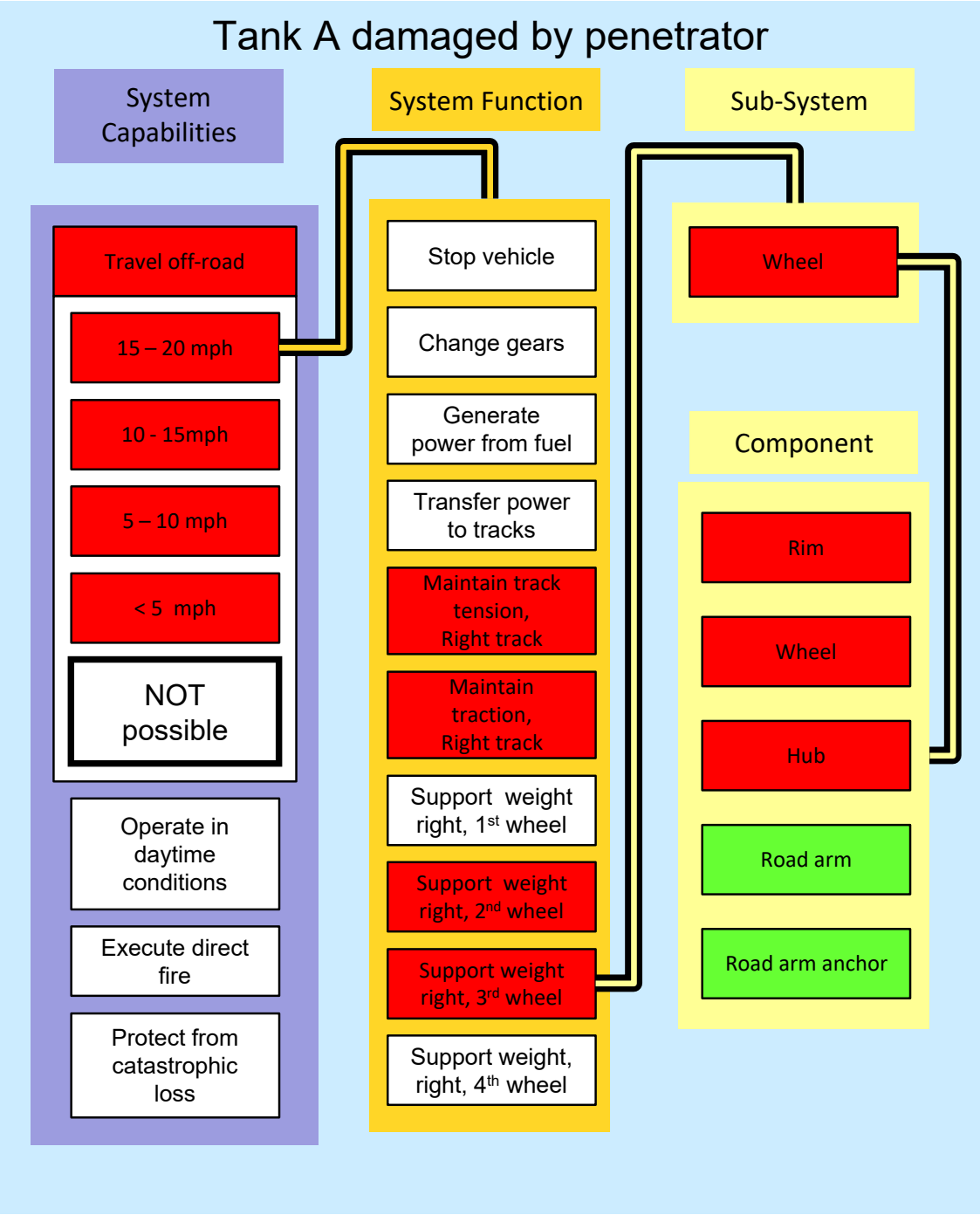


Figure A.1: Representative functional skeleton of a military tank presented by Agan. *Used with permission of the author.* [10, 11, figure 21]

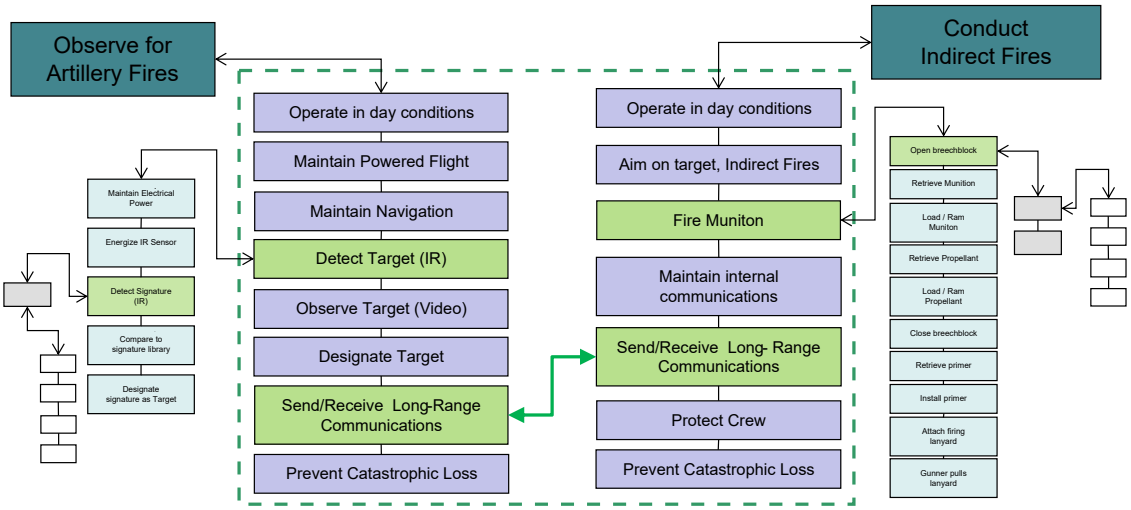


Figure A.2: Example of linking system capabilities within a system-of-system construct. *Used with permission of the author.* [10, 11, figure 28]

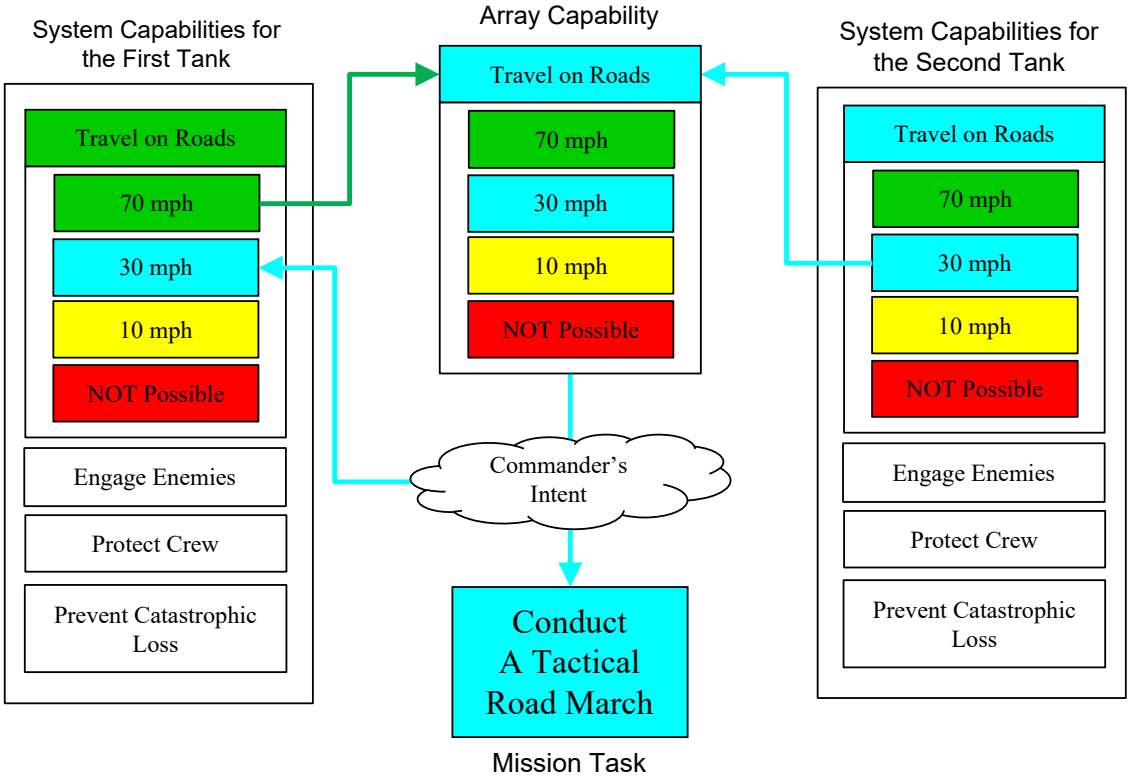


Figure A.3: Aggregation of system capabilities at the SOS level. *Used with permission of the author.* [10, 11, figure 16]

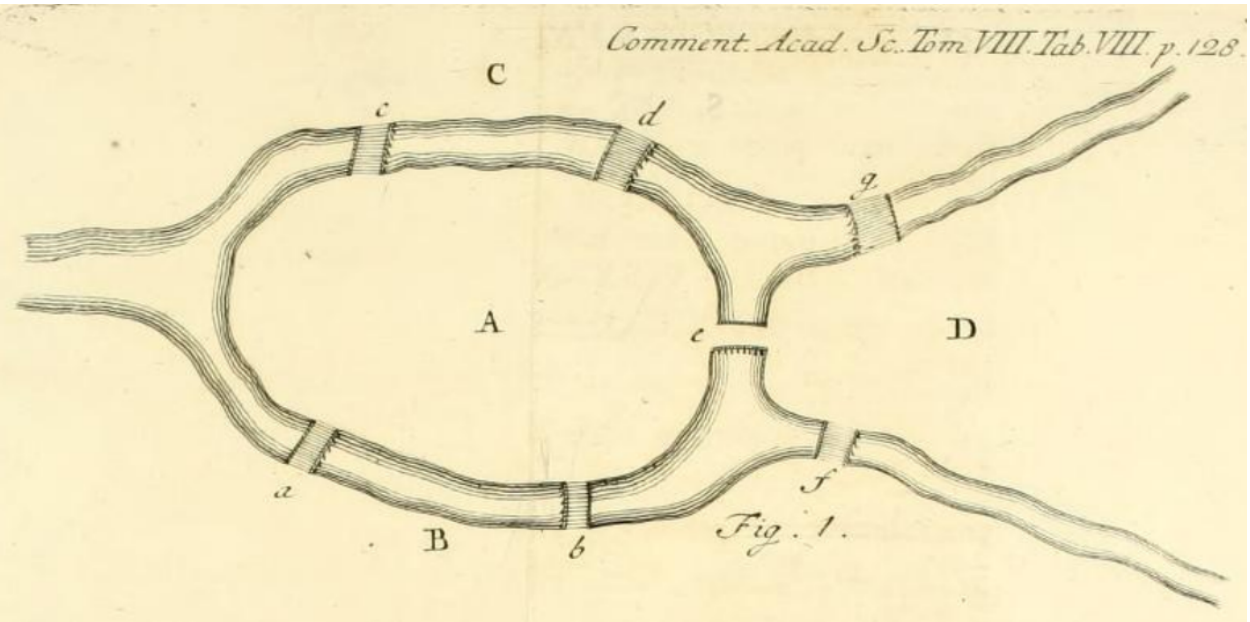


Figure A.4: Euler's depiction of the Kneiphof and its seven bridges at Königsberg [12].

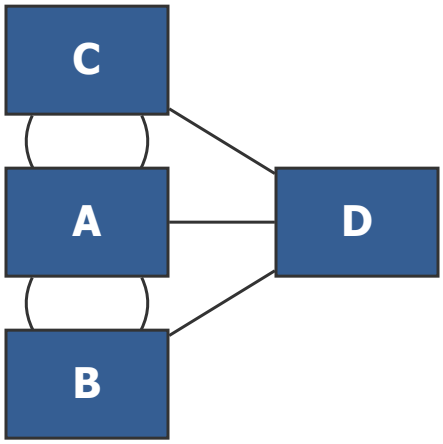


Figure A.5: Graphical representation of the Kneiphof and its seven bridges at Königsberg using Euler's notation.

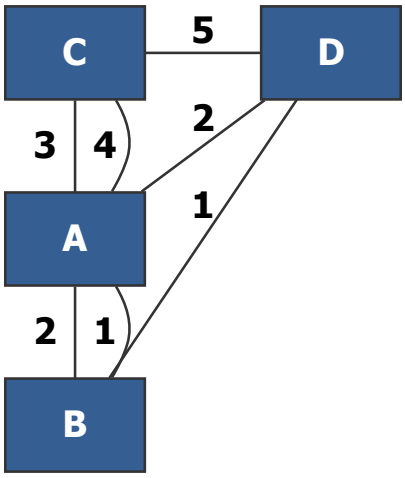


Figure A.6: Weighted analogue of Euler's Königsberg graph.

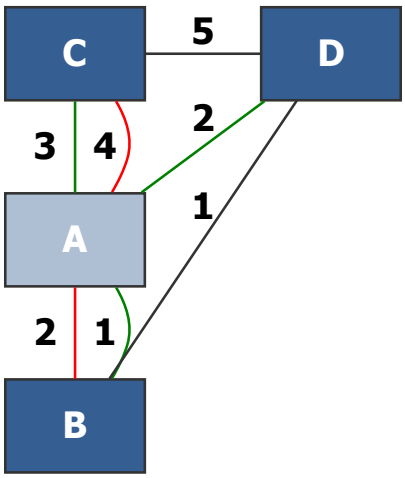


Figure A.7: Visiting vertex `A`. The shortest path to each adjacent vertex is shown in green; longer paths are shown in red.

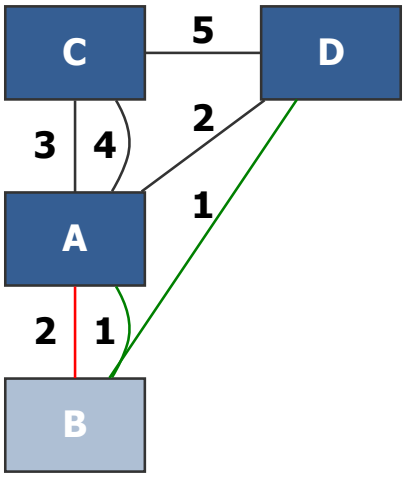


Figure A.8: Visiting vertex `B`. The shortest path to each adjacent vertex is shown in green; longer paths are shown in red.

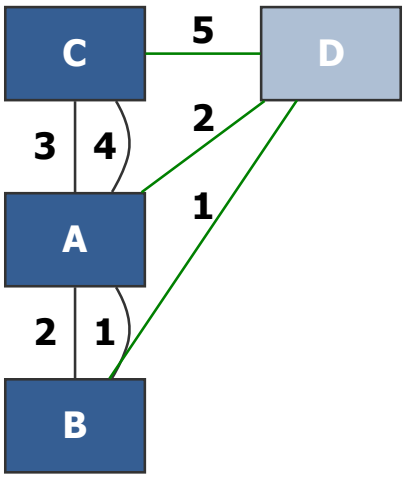


Figure A.9: Visiting vertex `D`. The shortest path to each adjacent vertex is shown in green; longer paths are shown in red.

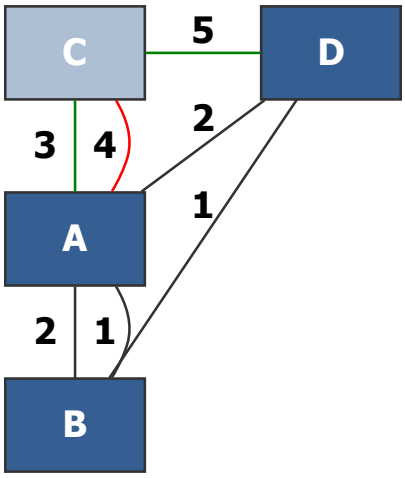


Figure A.10: Visiting vertex `C`. The shortest path to each adjacent vertex is shown in green; longer paths are shown in red.

A.3 Chapter 3

PARNO	PARATITLE	LDUIC	LN	GRADE	MOSLIN	ERC	TITLENOMEN	BRNCH	REQ	AUTH
306	RECOVERY SECTION		01	E6	91B3O		RECOVERY VEH SUPV	OD	1	1
306	RECOVERY SECTION		02	E5	91B2O		RECOVERY VEH OPR	OD	1	1
306	RECOVERY SECTION		03	E5	91E2O		ALLIED TRADES SPEC	OD	1	1
306	RECOVERY SECTION		04	E5	91E2O		ALLIED TRADES SPEC	OD	1	1
306	RECOVERY SECTION		05	E4	91B1O		RECOVERY VEH OPR	OD	1	1
306	RECOVERY SECTION		06	E3	91E1O		ALLIED TRADES SPEC	OD	1	1
306	RECOVERY SECTION				A24463	A	AIR CONDITIONER: FL/WALL A/C AC 208\		1	1
306	RECOVERY SECTION				B49272	A	BAYONET-KNIFE: W/SCABBARD FOR M1(		6	6
306	RECOVERY SECTION				C05002	A	COMPUTER SYS DIGITAL: AN/PYQ-10(C)		3	3
306	RECOVERY SECTION				C06935	A	CARBINE 5.56 MILLIMETER: M4A1		6	6
306	RECOVERY SECTION				C18278	A	COMPUTER SYSTEM: DIGITAL AN/UYQ-9		2	2
306	RECOVERY SECTION				T62359	A	TRUCK VAN: M1079A1P2 WO/WINCH		1	1
306	RECOVERY SECTION				T63161	P	TRUCK WRECKER: M984A4		1	1
306	RECOVERY SECTION				T92889	A	MAINTENANCE SUPPORT DEVICE:		2	2
306	RECOVERY SECTION				T93761	A	TRAILER: PALLETIZED LOADING 8X20		1	1
306	RECOVERY SECTION				T94671	P	TRUCK WRECKER:		1	1
306	RECOVERY SECTION				T96564	A	TRAILER FLAT BED: M1082 TRLR CARGO		1	1

Figure A.11: Excerpt from a typical MTOE document.

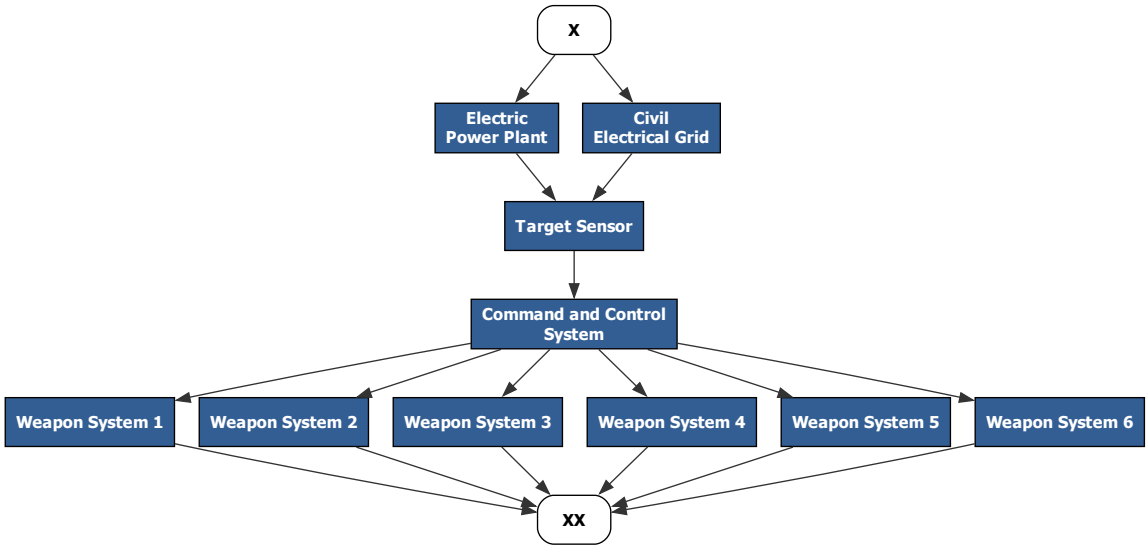


Figure A.12: Case study SOS fault tree. *Note: the civil electrical grid is not included in the case study.*

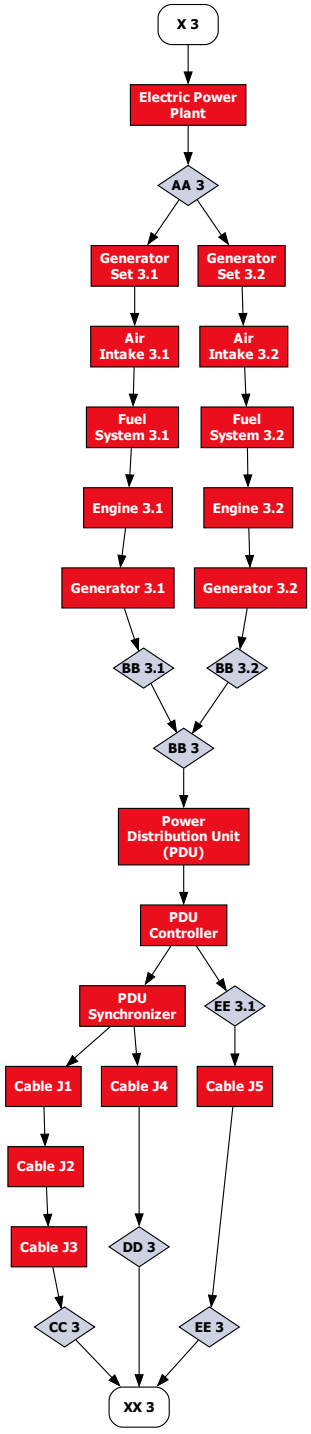


Figure A.13: Example system graph.

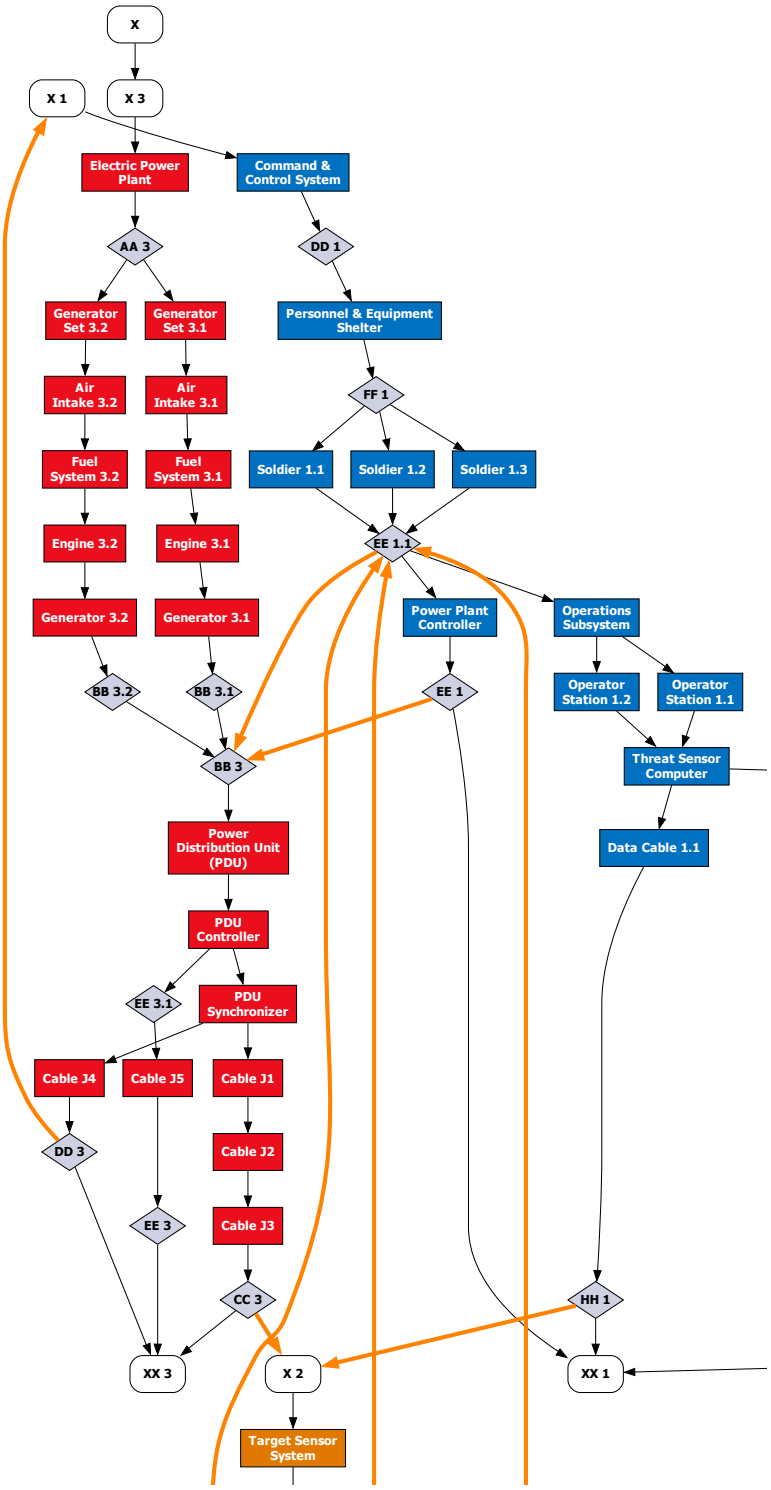


Figure A.14: A portion of an SOS graph showing inter-system capability edge connections (in orange).

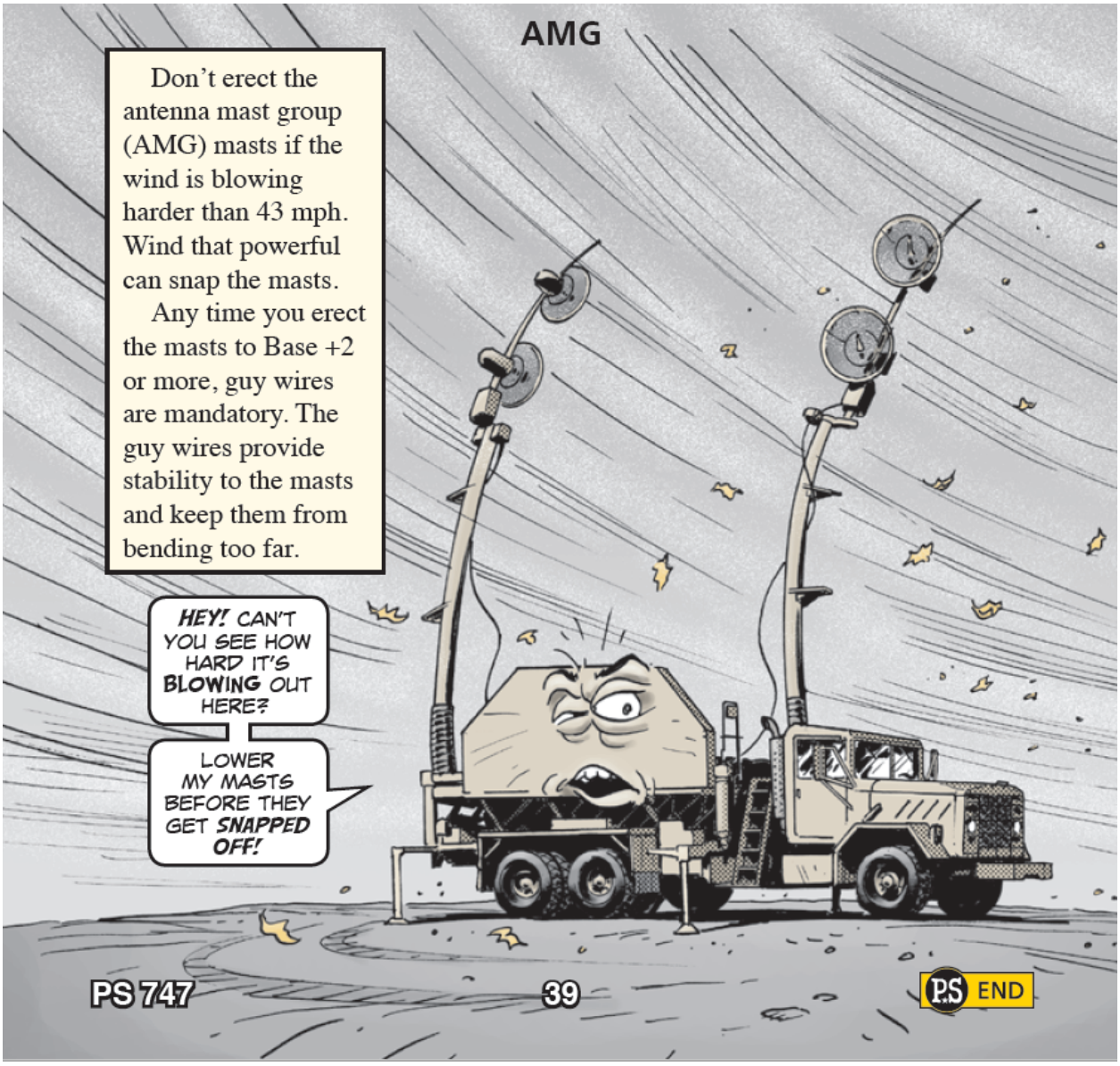


Figure A.15: Excerpt from TB 43-PS-747, *The Preventative Maintenance Monthly*, showing a windspeed value above which a communications antenna may experience damage or failure [13, p. 39]. *Used with editor's permission.*

A.4 Chapter 4

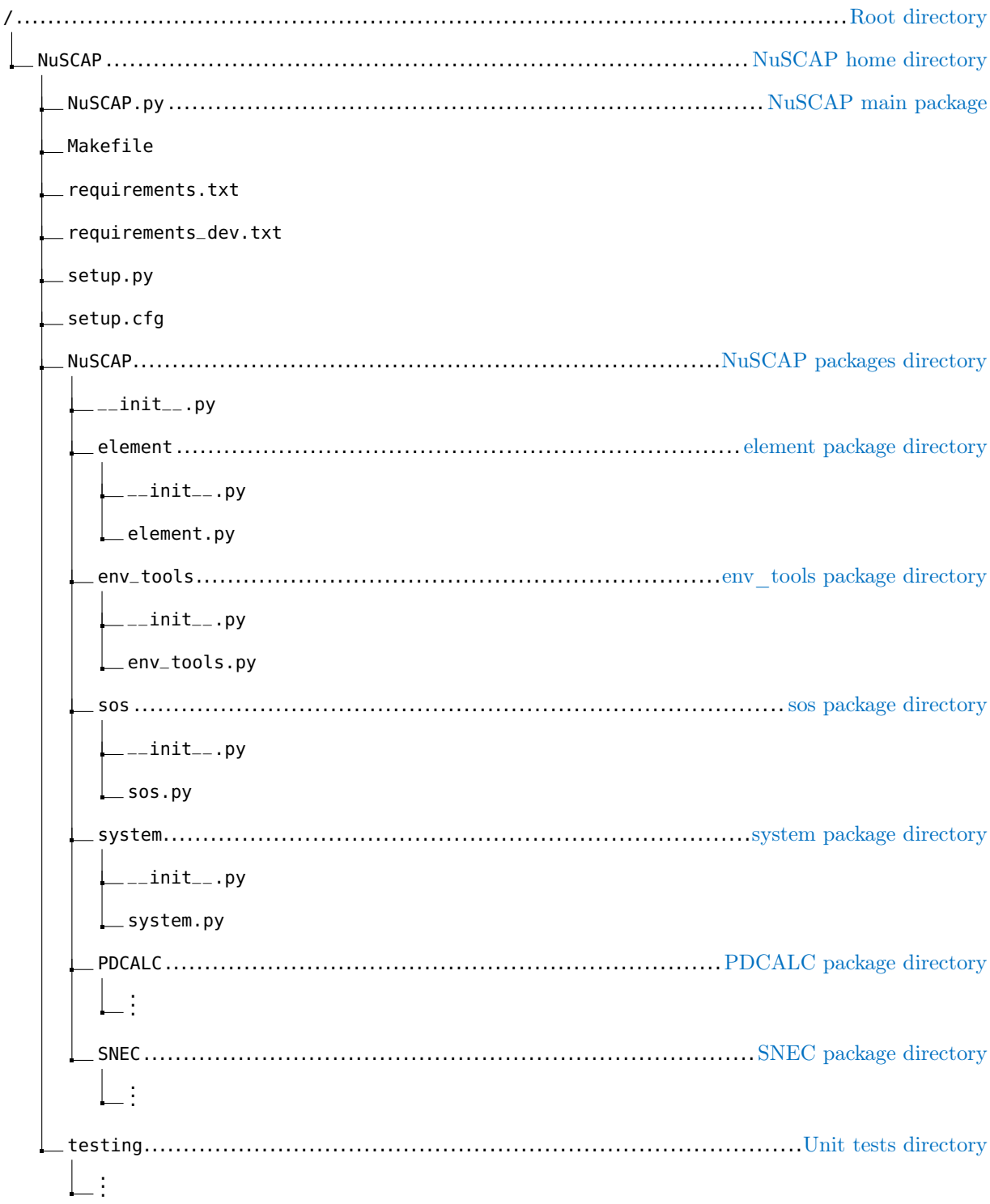


Figure A.16: Standard NuSCAP application directory structure.

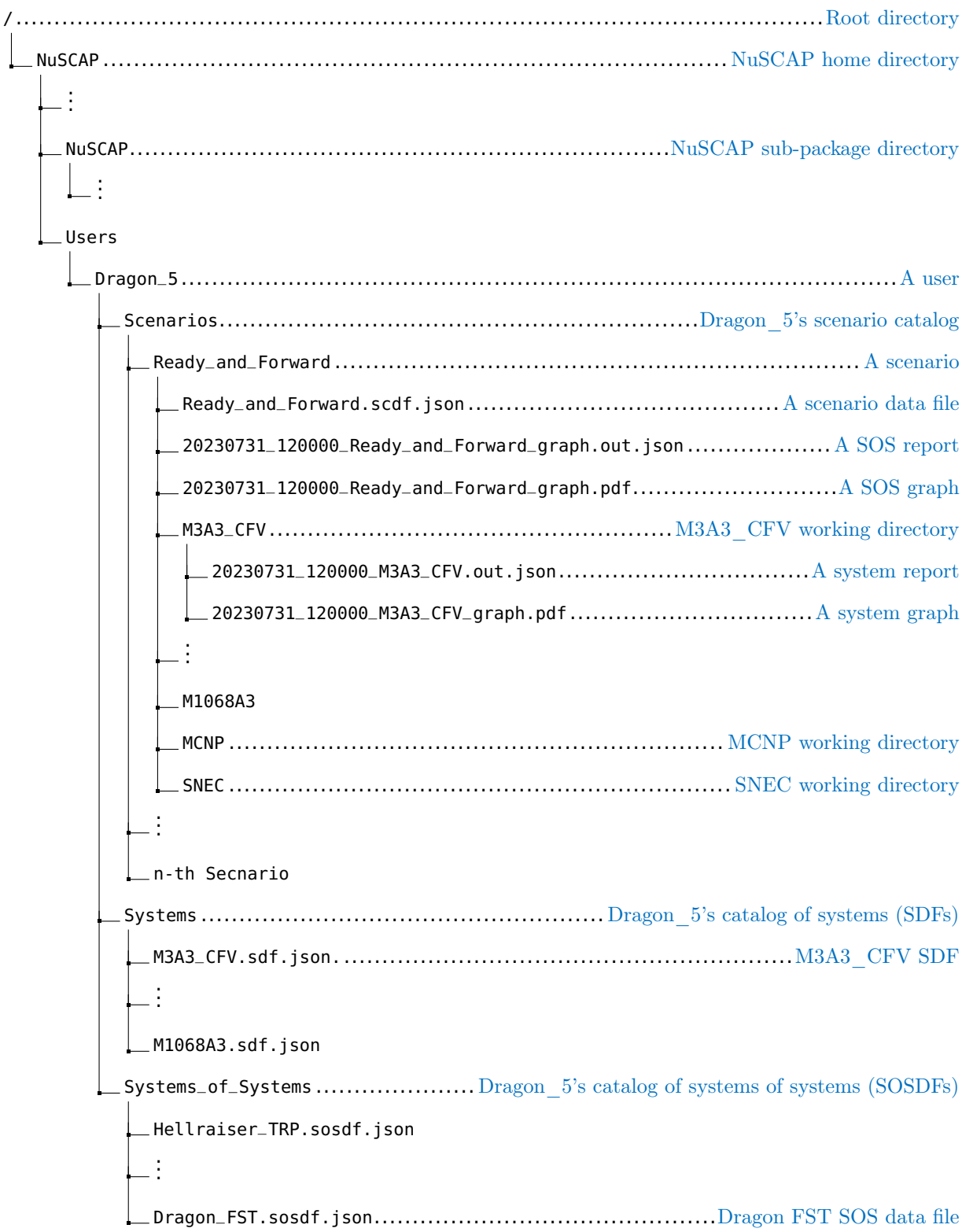


Figure A.17: Suggested user directory structure.

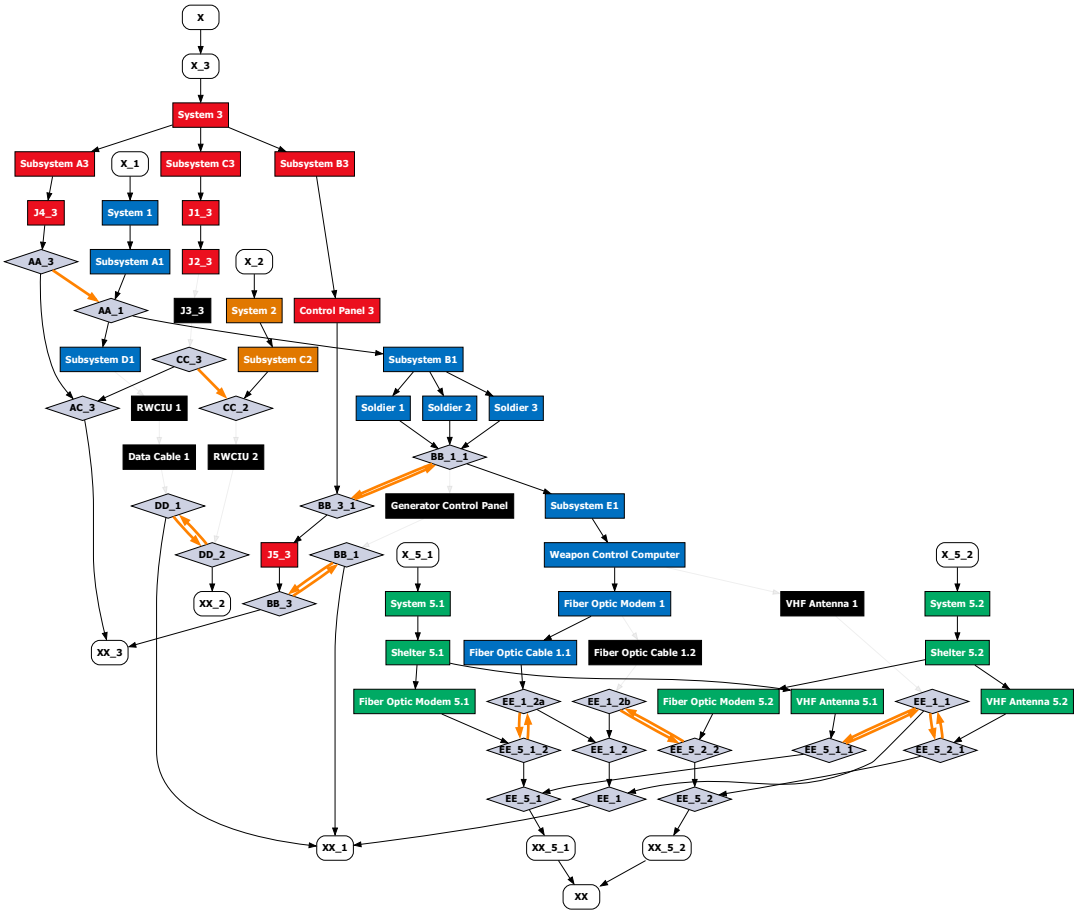


Figure A.18: An example of the SOS graph produced by a NuSCAP application run during unit testing of the application. Dysfunctional nodes are black with white text. Removed edges are depicted in pale gray.

A.5 Chapter 5



Figure A.19: A macroscopic view of the case study SOS deployment formation near the Trinity test site. Image produced with Google Earth Pro v. 7.3.6.9345 [14].

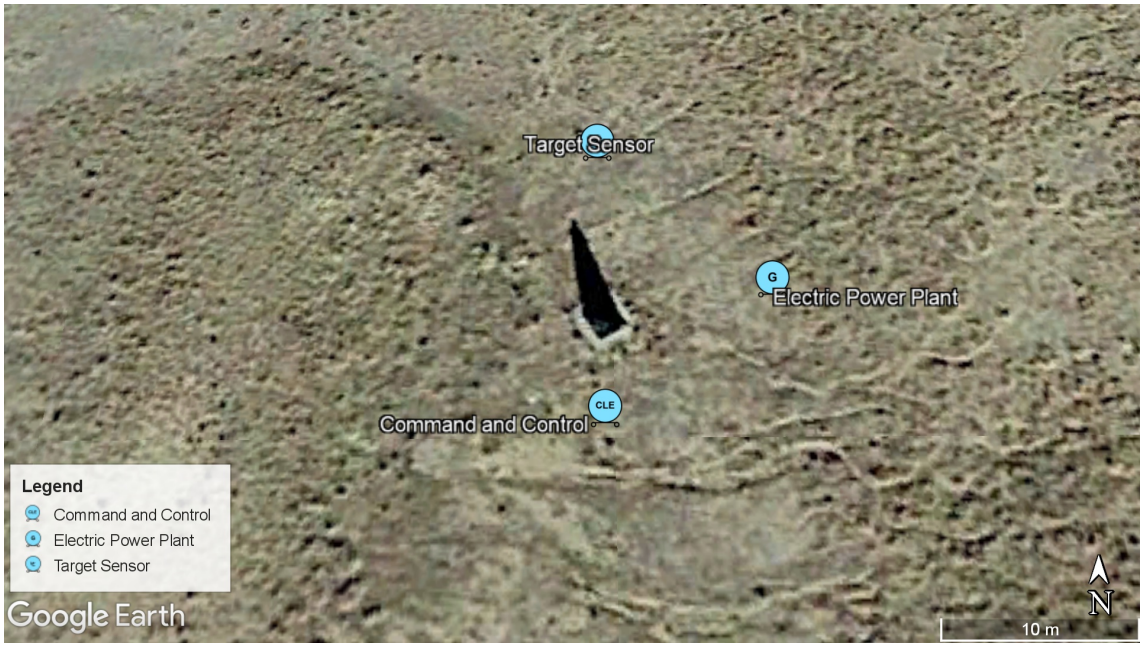


Figure A.20: An enlarged view of the concentrated command and control, target sensor, and electric power generation system area within the case study SOS formation. Image produced with Google Earth Pro v. 7.3.6.9345 [14].

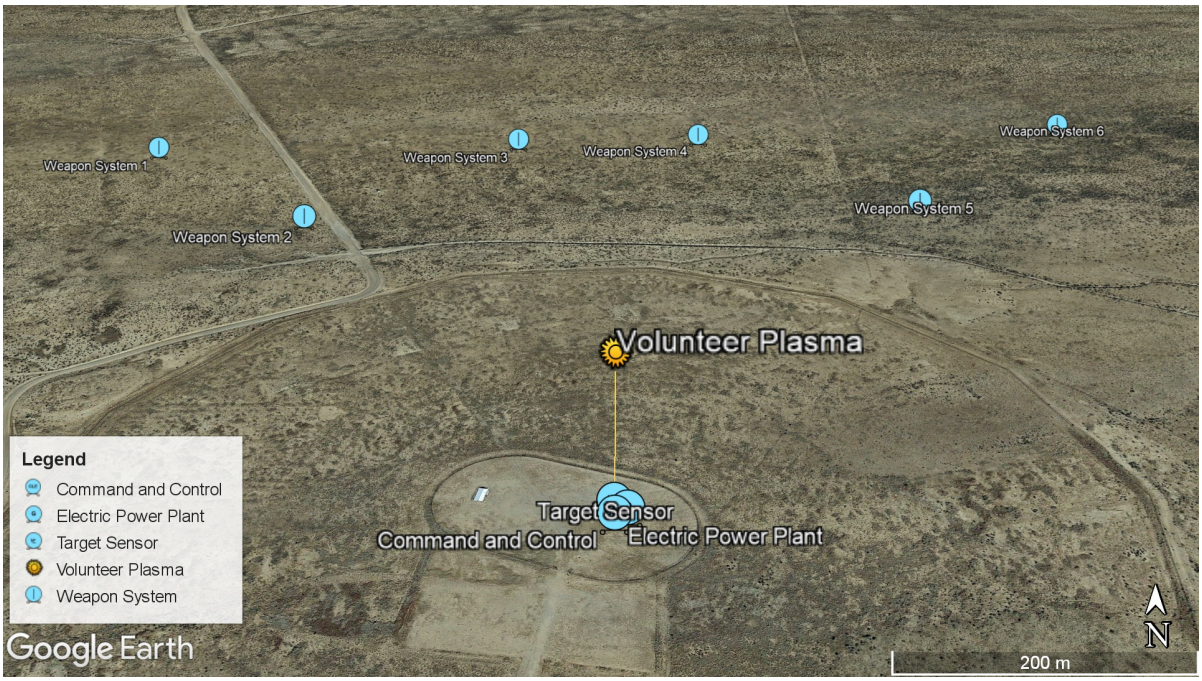


Figure A.21: Volunteer Plasma scenario with the nuclear detonation overhead the command and control, target sensor, and electric power plant systems. Image produced with Google Earth Pro v. 7.3.6.9345 [14].

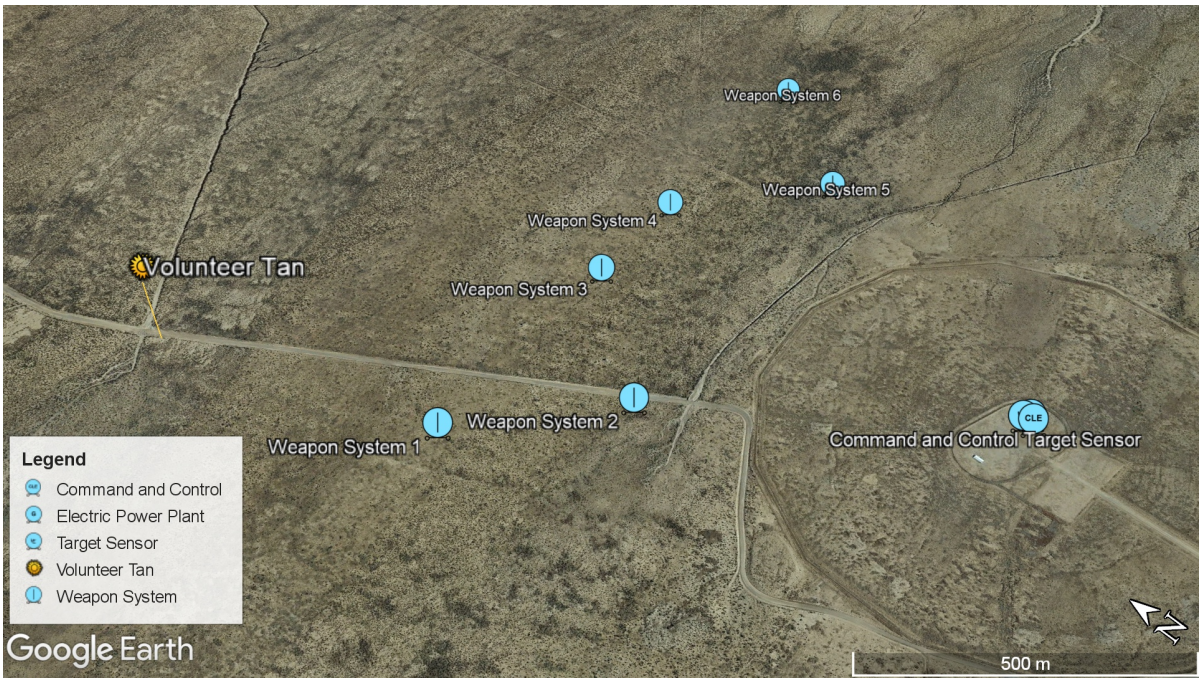


Figure A.22: Volunteer Tan scenario with the nuclear detonation located 1.5 km north-northwest of the target sensor system. Image produced with Google Earth Pro v. 7.3.6.9345 [14].



Figure A.23: Volunteer Sunrise scenario with the nuclear detonation positioned 3.9 km northeast of the target sensor system. Image produced with Google Earth Pro v. 7.3.6.9345 [14].

A.6 Chapter 6

Chapter 6 contains no figures.

Appendix B

Tables

B.1 Chapter 1

Chapter 1 contains no tables.

B.2 Chapter 2

Table B.1: Zeroth step of Dijkstra's algorithm.

Vertex	Distance from `A`	Previous Vertex
`A`	0	
`B`	∞	
`C`	∞	
`D`	∞	

Table B.2: First step of Dijkstra's algorithm.

Vertex	Distance from `A`	Previous Vertex
`A`	0	
`B`	1	
`C`	3	
`D`	2	

B.3 Chapter 3

Table B.3: Example capability bins and traversal paths.

Performance Bin	Path	Boolean Condition
Powers System 2 with either generator set	`X 3 → CC 3`	True
Powers System 2 with generator set 1 only	`X 3 → BB 3.1`	True
	`X 3 → BB 3.2`	False
	`X 3 → CC 3`	True
Powers System 2 with generator set 2 only	`X 3 → BB 3.1`	False
	`X 3 → BB 3.2`	True
	`X 3 → CC 3`	True
Not possible	`X3 → CC 3`	False

B.4 Chapter 4

Table B.4: NuSCAP `element` object properties.

Property	Description	Type	User Input Required
`name`	Unique string representing the `element` object	str	yes
`thresholds`	Dysfunction threshold values for nuclear weapon environment of interest; defaults = infinity (*see* table B.5 for units)	dict	yes
`functionality`	The functionality of the object expressed as a binary value; default = 1	int	no
`func_type`	String equivalent of functionality; default = functional	str	no
`vntk`	VNTK string (if available); default = None	str	yes
`rel_pos`	Cartesian position of the element relative to the geometric center of the bottom face of its parent system in meters; default = [0,0,0]	list	yes
`el_type`	Type of element: "equipment" or "human"	str	yes
`wpn_envs`	Magnitudes of nuclear weapon environments to which the element is exposed; defaults = 0 (*see* table B.5 for units.)	dict	no
`cause_of_dysfunction`	List of dysfunction thresholds exceeded by nuclear weapon environments	list	no
`range_to_gz`	Distance along the ground between the element and AGZ in meters	float	no
`elevation`	Ground elevation at the element's location in meters above MSL (see §3.3.3)	float	no
`tgt_depth`	Depth in meters below the surface of the ground or water at which the element is located; for buried targets only (see §3.3.3)	int	no

continued...

Table B.4 (continued): NuSCAP `element` object properties.

Property	Description	Type	User Input Required
`r95`	The radius that encompasses 95% of the constituent objects in an area target [44] (see §3.3.3)	float	yes
`azimuth`	The angular displacement in degrees measured clockwise between the true north vector and a vector from AGZ to the element [44]	float	no
`heading_deg`	The angular displacement in degrees measured clockwise between the true north vector and a vector normal to the element's front face (see §3.3.3)	float	yes
`abs_pos`	Cartesian position of the element relative to the point of the nuclear detonation in meters	list	no

Table B.5: Nuclear weapon environment units in NuSCAP.

Nuclear Weapon Environment	NuSCAP Units
static overpressure	psi
dynamic pressure	psi
windspeed	$m \cdot s^{-1}$
thermal fluence	$cal \cdot cm^{-2}$
total dose	rad(tissue)
neutron dose	rad(tissue) rad(Si)
neutron fluence	1 MeV neutrons$\cdot cm^{-2}$
gamma ray dose	rad(tissue) rad(Si)
gamma ray dose rate	rad(Si)$\cdot s^{-1}$
PD	None

Table B.6: NuSCAP `system` object properties.

Property	Description	Type	User Input Required
`name`	Unique string representing the `system` object	str	yes
`sdf`	Path to the system's SDF	str	yes
`scenario_data`	Path to the ScDF being studied	str	yes
`functionality`	The functionality of the object expressed as a binary value; default = 1	int	no
`func_type`	String equivalent of functionality; default = functional	str	no
`elements`	`element` objects that compose the `system`	dict	yes
`residual_capabilities`	Maximum system capabilities remaining after exposure to nuclear weapon environments	dict	no
`location`	MGRS coordinates locating the geometric center of the bottom face of the physical system (see §3.3.3)	str	yes
`range_to_gz`	Distance along the ground between the system and AGZ in meters	float	no
`elevation`	Ground elevation at the system's location in meters above MSL (see §3.3.3)	float	yes
`heading_deg`	The angular displacement in degrees measured clockwise between the true north vector and a vector normal to the system's front face (see §3.3.3)	float	yes
`azimuth`	The angular displacement in degrees measured clockwise between the true north vector and a vector from AGZ to the system [44]	float	no

Table B.7: NuSCAP `sos` object properties.

Property	Description	Type	User Input Required
`name`	String representing the `sos` object	str	yes
`sosdf`	Path to the SOSDF	str	yes
`scenario_data`	Path to the ScDF	str	yes
`functionality`	The functionality of the object expressed as a binary value; default = 1	int	no
`func_type`	String equivalent of functionality; default = functional	str	no
`elements`	`element` objects that compose the SOS	dict	no
`systems`	`system` objects that compose the SOS	dict	yes
`residual_capabilities`	Maximum SOS capabilities remaining after exposure to nuclear weapon environments	dict	no

Table B.8: NuSCAP `env_tools` properties.

Property	Description	Type	User Input Required
`sos`	The name of the SOS being analyzed	str	yes
`scenario_data`	Path to the ScDF	str	yes
`yld_kt`	The threat weapon yield specified in the ScDF (see §3.3.2)	str	yes
`hob_ft`	The HOB specified in meters in the ScDF; converted to feet	float	no
`hob_m`	The HOB specified in the ScDF (see §3.3.2)	float	yes
`hob_sigma_ft`	The HOB sigma specified in meters in the ScDF; converted to feet (see §3.3.2)	float	no
`cep_ft`	The CEP specified in meters in the ScDF; converted to feet (see §3.3.2)	float	no
`vis_m`	Atmospheric visibility specified in kilometers in the ScDF; converted to meters (see §3.3.3)	float	no

B.5 Chapter 5

Table B.9: Mean dysfunction threshold values by `element` subtype.

Nuclear Weapon Environment	Units	Personnel	Electrical	Mechanical	Fiber Optics	Antenna	Weapon	Ordnance
Static Overpressure	psi	25	7	20	20	7	20	7
Dynamic Pressure	psi	∞	1	5	5	1	10	2
Windspeed	$m \cdot s^{-1}$	∞	∞	∞	∞	20	40	∞
Thermal Fluence	$cal \cdot cm^2$	∞	200	∞	∞	200	∞	200
Total Dose	rad[1]	3000	10^6	∞	1000	10^6	∞	10^6
Neutron Dose	rad	∞	∞	∞	∞	∞	∞	∞
Neutron Fluence	$cm^{-2} \cdot s^{-1}$	∞	10^{12}	∞	∞	10^{12}	∞	10^{12}
Gamma Ray Dose	rad	∞	∞	∞	∞	∞	∞	∞
Gamma Ray Dose Rate	$rad(Si) \cdot s^{-1}$	∞	10^{10}	∞	∞	10^{10}	∞	10^{10}
PD		0.5[2]	∞	∞	∞	∞	∞	∞

[1] Units of rad here includes units of rad(tissue) for humans and rad(Si) for equipment.
[2] PD values were not fuzzed like other threshold values. These remained fixed at 0.5 for all simulations in this study.

Table B.10: Volunteer Tan weapon system elemental dysfunction statistics.

Weapon System	Ground Range to AGZ	Dysfunctional Elements	Causes of Dysfunction	Dysfunctional Elements by Cause
1	575 m	54/67 (80.6%)	static overpressure	51
			dynamic pressure	53
			windspeed	3
			thermal fluence	1
2	879 m	22/67 (32.8%)	static overpressure	19
			dynamic pressure	17
			windspeed	3
3	819 m	39/67 (58.2%)	static overpressure	30
			dynamic pressure	30
			windspeed	3
4	1,007 m	15/67 (22.4%)	static overpressure	13
			dynamic pressure	1
			windspeed	3
5	1,343 m	3/67 (4.5%)	windspeed	3
6	1,432 m	5/67 (7.5%)	static overpressure	2
			windspeed	3
Total		138/402 (34.3%)	static overpressure	115
			dynamic pressure	101
			windspeed	18
			thermal fluence	1

B.6 Chapter 6

Chapter 6 contains no tables.

Appendix C

Graph Traversal Verification

By way of proof, a number of simple graphs are presented in the figures that follow depicting serial, parallel, and combined relationships of functional and dysfunctional elements (vertices). With each type of graph, a short Python script that employs the NetworkX `has_path` algorithm is presented. These scripts evaluate all states of the given graph type and provide the result of the `networkx.has_path` evaluation for each state. The `networkx.has_path` method traverses each graph according to Dijkstra's algorithm (see §2.3.2), seeking a viable path from vertex `X` to vertex `XX`. Each combination of functional and dysfunctional vertices within the graph are then presented with the arithmetic evaluation of the same graph to demonstrate agreement.

Throughout this appendix, functional nodes hold a score of '1' and are filled dark blue; conversely, dysfunctional nodes hold a score of '0' and are filled black. Following the same method employed in the NuSCAP application, all incident edges are removed from each dysfunctional vertex. These removed edges are depicted in pale gray to show the path(s) present prior to dysfunction.

All file listings are attached to the electronic PDF version of this document.

C.1 Two Serial Elements

Adhering to Agan [10], the functionality of a serial graph j is$A_j = \prod_i^n (E_i)$ where E_i is the functionality of element i.

Thus, the functionality of the graph in figure C.1a is

$$\begin{aligned} A_{C.1a} &= \prod_{i=1}^{2}(E_i) \\ &= 1 \times 1 \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.1b is

$$\begin{aligned} A_{C.1b} &= \prod_{i=1}^{2}(E_i) \\ &= 0 \times 1 \\ &= 0 \therefore \text{dysfunctional.} \end{aligned}$$

The functionality of the graph in figure C.1c is

$$\begin{aligned} A_{C.1c} &= \prod_{i=1}^{2}(E_i) \\ &= 1 \times 0 \\ &= 0 \therefore \text{dysfunctional.} \end{aligned}$$

The functionality of the graph in figure C.1d is

$$\begin{aligned} A_{C.1d} &= \prod_{i=1}^{2}(E_i) \\ &= 0 \times 0 \\ &= 0 \therefore \text{dysfunctional.} \end{aligned}$$

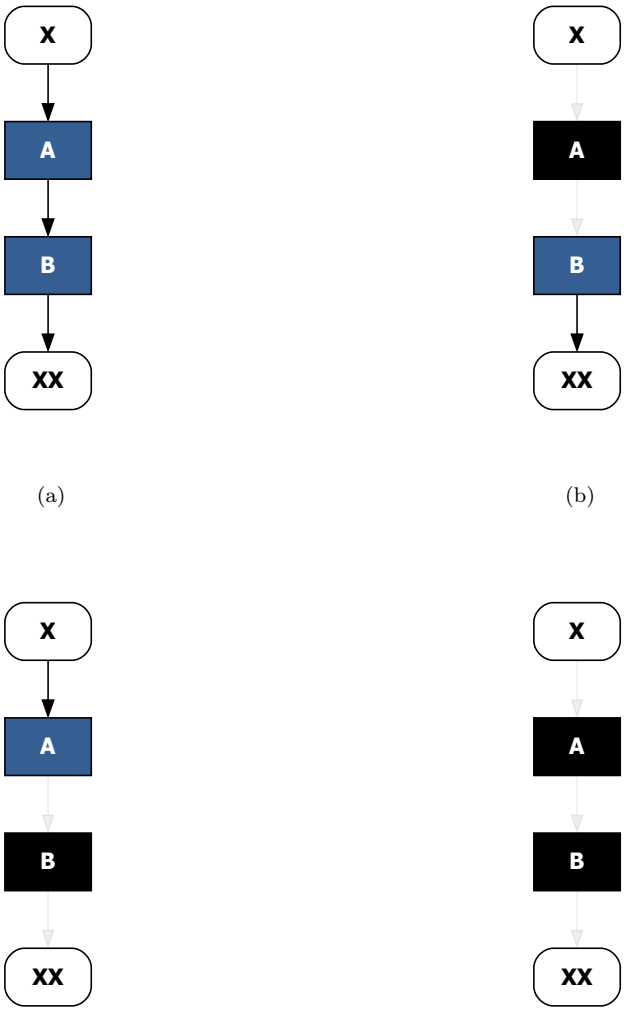


Figure C.1: Graphs of two serial elements in various functional states.

Listing C.1: Series graphs evaluation (series.nx.py)

```
import networkx as nx

serial = nx.DiGraph()
serial.add_nodes_from(["X", "XX", "A", "B"])
serial.add_edges_from([("X", "A"), ("A", "B"), ("B", "XX")])

dysf_nodes = [[None], ["A"], ["B"], ["A", "B"]]

for node_list in dysf_nodes:
    dysf_node_string = str()
    for node in node_list:
        dysf_edges = []
        for edge in serial.edges:
            if node in edge:
                dysf_edges.append(edge)
        for edges in dysf_edges:
            serial.remove_edges_from([edges])
        dysf_node_string = dysf_node_string + f" {node}"
    if nx.has_path(serial, "X", "XX") == True:
        print(
            "A path DOES exist between vertices 'X' and 'XX'"
            + " in the serial graph with dysfunctional"
            + f" vertices{dysf_node_string}.\n"
        )
    else:
        print(
            "A path DOES NOT exist between vertices 'X' and 'XX'"
            + " in the serial graph with dysfunctional"
            +f" vertices{dysf_node_string}.\n"
        )
    serial = nx.DiGraph()
    serial.add_nodes_from(["X", "XX", "A", "B"])
    serial.add_edges_from([("X", "A"), ("A", "B"), ("B", "XX")])
```

Listing C.2: Series graphs evaluation output (series.nx.out)

```
A path DOES exist between vertices 'X' and 'XX' in the serial graph with dysfunctional vertices None.

A path DOES NOT exist between vertices 'X' and 'XX' in the serial graph with dysfunctional vertices A.

A path DOES NOT exist between vertices 'X' and 'XX' in the serial graph with dysfunctional vertices B.

A path DOES NOT exist between vertices 'X' and 'XX' in the serial graph with dysfunctional vertices A B.
```

C.2 Two Parallel Elements

Adhering to Agan [10], the functionality of a parallel graph j is$A_j = 1 - \prod_i^n (1 - B_i)$ where B_i is the functionality of branch i.

Thus, the functionality of the graph in figure C.2a is

$$\begin{aligned} A_{C.2a} &= 1 - \prod_{i=1}^{2} (1 - B_i) \\ &= 1 - [(1 - 1) \times (1 - 1)] \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.2b is

$$\begin{aligned} A_{C.2b} &= 1 - \prod_{i=1}^{2} (1 - B_i) \\ &= 1 - [(1 - 0) \times (1 - 1)] \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.2c is

$$\begin{aligned} A_{C.2c} &= 1 - \prod_{i=1}^{2} (1 - B_i) \\ &= 1 - [(1 - 1) \times (1 - 0)] \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.2d is

$$\begin{aligned} A_{C.2d} &= 1 - \prod_{i=1}^{2} (1 - B_i) \\ &= 1 - [(1 - 0) \times (1 - 0)] \\ &= 0 \therefore \text{dysfunctional.} \end{aligned}$$

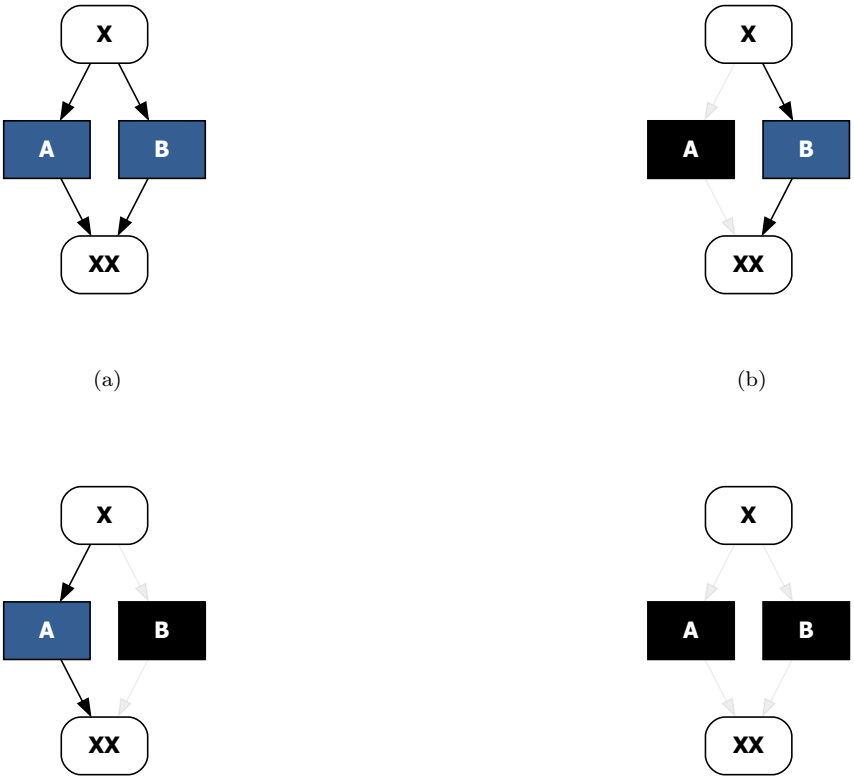


Figure C.2: Graphs of two parallel elements in various functional states.

Listing C.3: Parallel graphs evaluation (parallel.nx.py)

```
import networkx as nx

parallel = nx.DiGraph()
parallel.add_nodes_from(["X", "XX", "A", "B"])
parallel.add_edges_from([("X", "A"), ("X", "B"), ("A", "XX"), ("B", "XX")])

dysf_nodes = [[None], ["A"], ["B"], ["A", "B"]]

for node_list in dysf_nodes:
    dysf_node_string = str()
    for node in node_list:
        dysf_edges = []
        for edge in parallel.edges:
            if node in edge:
                dysf_edges.append(edge)
        for edges in dysf_edges:
            parallel.remove_edges_from([edges])
        dysf_node_string = dysf_node_string + f" {node}"
    if nx.has_path(parallel, "X", "XX") == True:
        print(
            "A path DOES exist between vertices 'X' and 'XX'"
            + " in the parallel graph with dysfunctional"
            + f" vertices{dysf_node_string}.\n"
        )
    else:
        print(
            "A path DOES NOT exist between vertices 'X' and 'XX'"
            + " in the parallel graph with dysfunctional"
            +f" vertices{dysf_node_string}.\n"
        )
    parallel = nx.DiGraph()
    parallel.add_nodes_from(["X", "XX", "A", "B"])
    parallel.add_edges_from([("X", "A"), ("X", "B"), ("A", "XX"), ("B", "XX")])
```

Listing C.4: Parallel graphs evaluation output (parallel.nx.out)

```
A path DOES exist between vertices 'X' and 'XX' in the parallel graph with dysfunctional vertices None
.
A path DOES exist between vertices 'X' and 'XX' in the parallel graph with dysfunctional vertices A
.
A path DOES exist between vertices 'X' and 'XX' in the parallel graph with dysfunctional vertices B
.
A path DOES NOT exist between vertices 'X' and 'XX' in the parallel graph with dysfunctional vertices A
    B
.
```

C.3 Two Parallel Elements in Series with a Third Element

The functionality of the graph in figure C.3a is

$$\begin{aligned} A_{C.3a} &= [1 - \prod_{i=1}^{2}(1 - B_i)] \times \prod_{i=3}^{3} E_i \\ &= [1 - [(1 - 1) \times (1 - 1)]] \times 1 \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.3b is

$$\begin{aligned} A_{C.3b} &= [1 - \prod_{i=1}^{2}(1 - B_i)] \times \prod_{i=3}^{3} E_i \\ &= [1 - [(1 - 0) \times (1 - 1)]] \times 1 \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.3c is

$$\begin{aligned} A_{C.3c} &= [1 - \prod_{i=1}^{2}(1 - B_i)] \times \prod_{i=3}^{3} E_i \\ &= [1 - [(1 - 1) \times (1 - 0)]] \times 1 \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.3d is

$$\begin{aligned} A_{C.3d} &= [1 - \prod_{i=1}^{2}(1 - B_i)] \times \prod_{i=3}^{3} E_i \\ &= [1 - [(1 - 1) \times (1 - 1)]] \times 0 \\ &= 0 \therefore \text{dysfunctional.} \end{aligned}$$

The functionality of the graph in figure C.3e is

$$\begin{aligned} A_{C.3e} &= [1 - \prod_{i=1}^{2}(1 - B_i)] \times \prod_{i=3}^{3} E_i \\ &= [1 - [(1 - 0) \times (1 - 0)]] \times 1 \\ &= 0 \therefore \text{dysfunctional.} \end{aligned}$$

The functionality of the graph in figure C.3f is

$$
\begin{aligned}
A_{C.3f} &= [1 - \prod_{i=1}^{2}(1 - B_i)] \times \prod_{i=3}^{3} E_i \\
&= [1 - [(1 - 0) \times (1 - 1)]] \times 0 \\
&= 0 \therefore \text{dysfunctional.}
\end{aligned}
$$

The functionality of the graph in figure C.3g is

$$
\begin{aligned}
A_{C.3g} &= [1 - \prod_{i=1}^{2}(1 - B_i)] \times \prod_{i=3}^{3} E_i \\
&= [1 - [(1 - 1) \times (1 - 0)]] \times 0 \\
&= 0 \therefore \text{dysfunctional.}
\end{aligned}
$$

The functionality of the graph in figure C.3h is

$$
\begin{aligned}
A_{C.3h} &= [1 - \prod_{i=1}^{2}(1 - B_i)] \times \prod_{i=3}^{3} E_i \\
&= [1 - [(1 - 0) \times (1 - 0)]] \times 0 \\
&= 0 \therefore \text{dysfunctional.}
\end{aligned}
$$

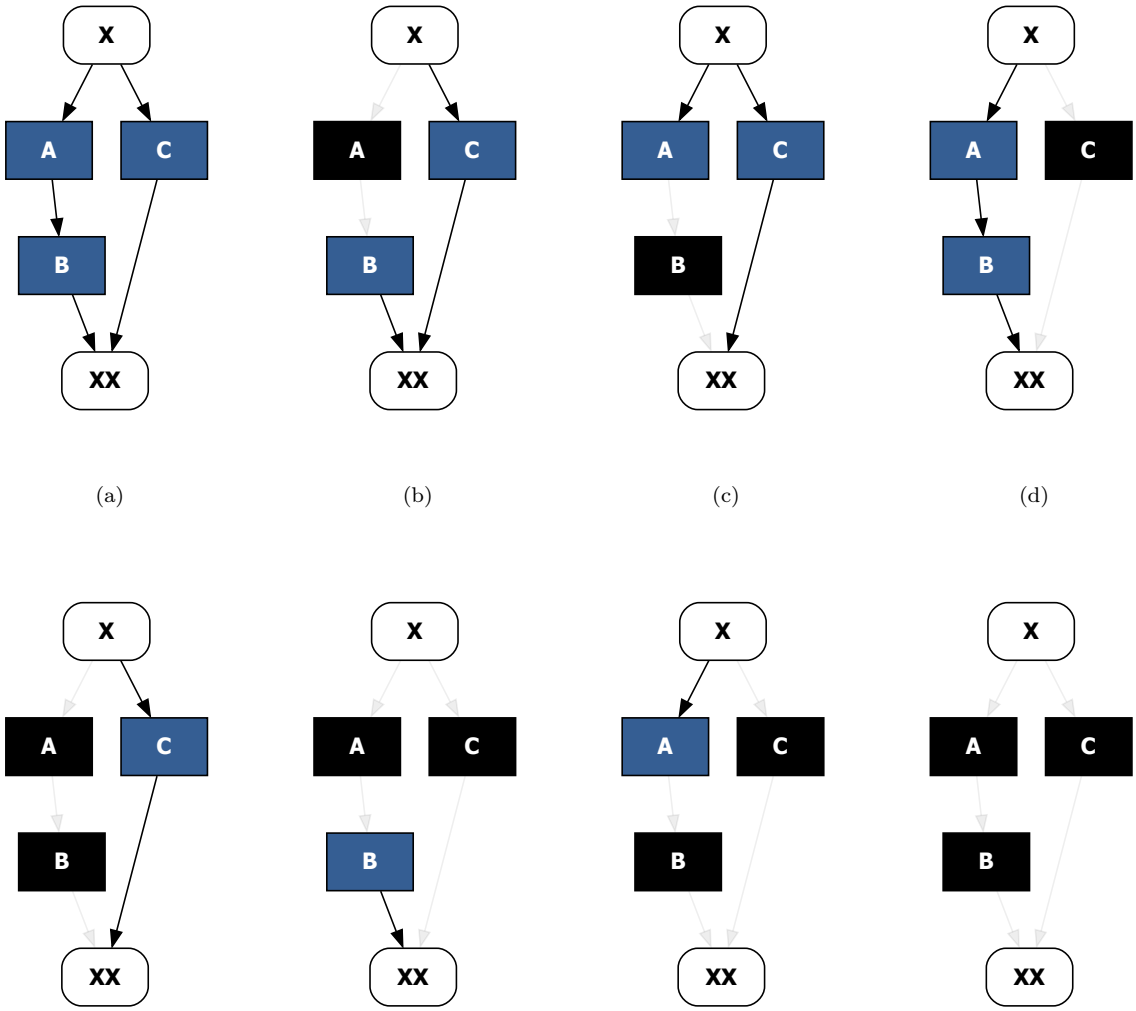


Figure C.3: Graphs of two parallel elements in series with a third element in various functional states.

Listing C.5: Parallel-serial graphs evaluation (parallel_series.nx.py)

```
import networkx as nx

parallel_series = nx.DiGraph()
parallel_series.add_nodes_from(["X", "XX", "A", "B", "C"])
parallel_series.add_edges_from(
    [("X", "A"), ("A", "B"), ("B", "XX"), ("X", "C"), ("C", "XX")]
)

dysf_nodes = [
    [None],
    ["A"],
    ["B"],
    ["C"],
    ["A", "B"],
    ["A", "C"],
    ["B", "C"],
    ["A", "B", "C"],
]

for node_list in dysf_nodes:
    dysf_node_string = str()
    for node in node_list:
        dysf_edges = []
        for edge in parallel_series.edges:
            if node in edge:
                dysf_edges.append(edge)
        for edges in dysf_edges:
            parallel_series.remove_edges_from([edges])
        dysf_node_string = dysf_node_string + f" {node}"
    if nx.has_path(parallel_series, "X", "XX") == True:
        print(
            "A path DOES exist between vertices 'X' and 'XX'"
            + " in the parallel-serial graph with dysfunctional"
            + f" vertices{dysf_node_string}.\n"
        )
    else:
        print(
            "A path DOES NOT exist between vertices 'X' and 'XX'"
            + " in the parallel-serial graph with dysfunctional"
            +f" vertices{dysf_node_string}.\n"
        )
    parallel_series = nx.DiGraph()
    parallel_series.add_nodes_from(["X", "XX", "A", "B", "C"])
    parallel_series.add_edges_from(
        [("X", "A"), ("A", "B"), ("B", "XX"), ("X", "C"), ("C", "XX")]
    )
```

Listing C.6: Parallel-serial graphs evaluation output (parallel_series.nx.out)

```
A path DOES exist between vertices 'X' and 'XX' in the parallel-serial graph with dysfunctional vertices
     None.

A path DOES exist between vertices 'X' and 'XX' in the parallel-serial graph with dysfunctional vertices
     A.
```

```
A path DOES exist between vertices 'X' and 'XX' in the parallel-serial graph with dysfunctional vertices B.

A path DOES exist between vertices 'X' and 'XX' in the parallel-serial graph with dysfunctional vertices C.

A path DOES exist between vertices 'X' and 'XX' in the parallel-serial graph with dysfunctional vertices A B.

A path DOES NOT exist between vertices 'X' and 'XX' in the parallel-serial graph with dysfunctional vertices A C.

A path DOES NOT exist between vertices 'X' and 'XX' in the parallel-serial graph with dysfunctional vertices B C.

A path DOES NOT exist between vertices 'X' and 'XX' in the parallel-serial graph with dysfunctional vertices A B C.
```

C.4 Two Serial Elements in Parallel with a Third Element

The functionality of the graph in figure C.4a is

$$\begin{aligned} A_{C.4a} &= 1 - \{[1 - \prod_{i=1}^{2} E_i] \times [1 - E_3]\} \\ &= 1 - \{[1 - (1 \times 1)] \times [1 - 1]\} \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.4b is

$$\begin{aligned} A_{C.4b} &= 1 - \{[1 - \prod_{i=1}^{2} E_i] \times [1 - E_3]\} \\ &= 1 - \{[1 - (0 \times 1)] \times [1 - 1]\} \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.4c is

$$\begin{aligned} A_{C.4c} &= 1 - \{[1 - \prod_{i=1}^{2} E_i] \times [1 - E_3]\} \\ &= 1 - \{[1 - (1 \times 0)] \times [1 - 1]\} \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.4d is

$$\begin{aligned} A_{C.4d} &= 1 - \{[1 - \prod_{i=1}^{2} E_i] \times [1 - E_3]\} \\ &= 1 - \{[1 - (1 \times 1)] \times [1 - 0]\} \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.4e is

$$\begin{aligned} A_{C.4e} &= 1 - \{[1 - \prod_{i=1}^{2} E_i] \times [1 - E_3]\} \\ &= 1 - \{[1 - (0 \times 0)] \times [1 - 1]\} \\ &= 1 \therefore \text{functional.} \end{aligned}$$

The functionality of the graph in figure C.4f is

$$
\begin{aligned}
A_{C.4f} &= 1 - \{[1 - \prod_{i=1}^{2} E_i] \times [1 - E_3]\} \\
&= 1 - \{[1 - (0 \times 1)] \times [1 - 0]\} \\
&= 0 \therefore \text{dysfunctional.}
\end{aligned}
$$

The functionality of the graph in figure C.4g is

$$
\begin{aligned}
A_{C.4g} &= 1 - \{[1 - \prod_{i=1}^{2} E_i] \times [1 - E_3]\} \\
&= 1 - \{[1 - (1 \times 0)] \times [1 - 0]\} \\
&= 0 \therefore \text{dysfunctional.}
\end{aligned}
$$

The functionality of the graph in figure C.4h is

$$
\begin{aligned}
A_{C.4h} &= 1 - \{[1 - \prod_{i=1}^{2} E_i] \times [1 - E_3]\} \\
&= 1 - \{[1 - (0 \times 0)] \times [1 - 0]\} \\
&= 0 \therefore \text{dysfunctional.}
\end{aligned}
$$

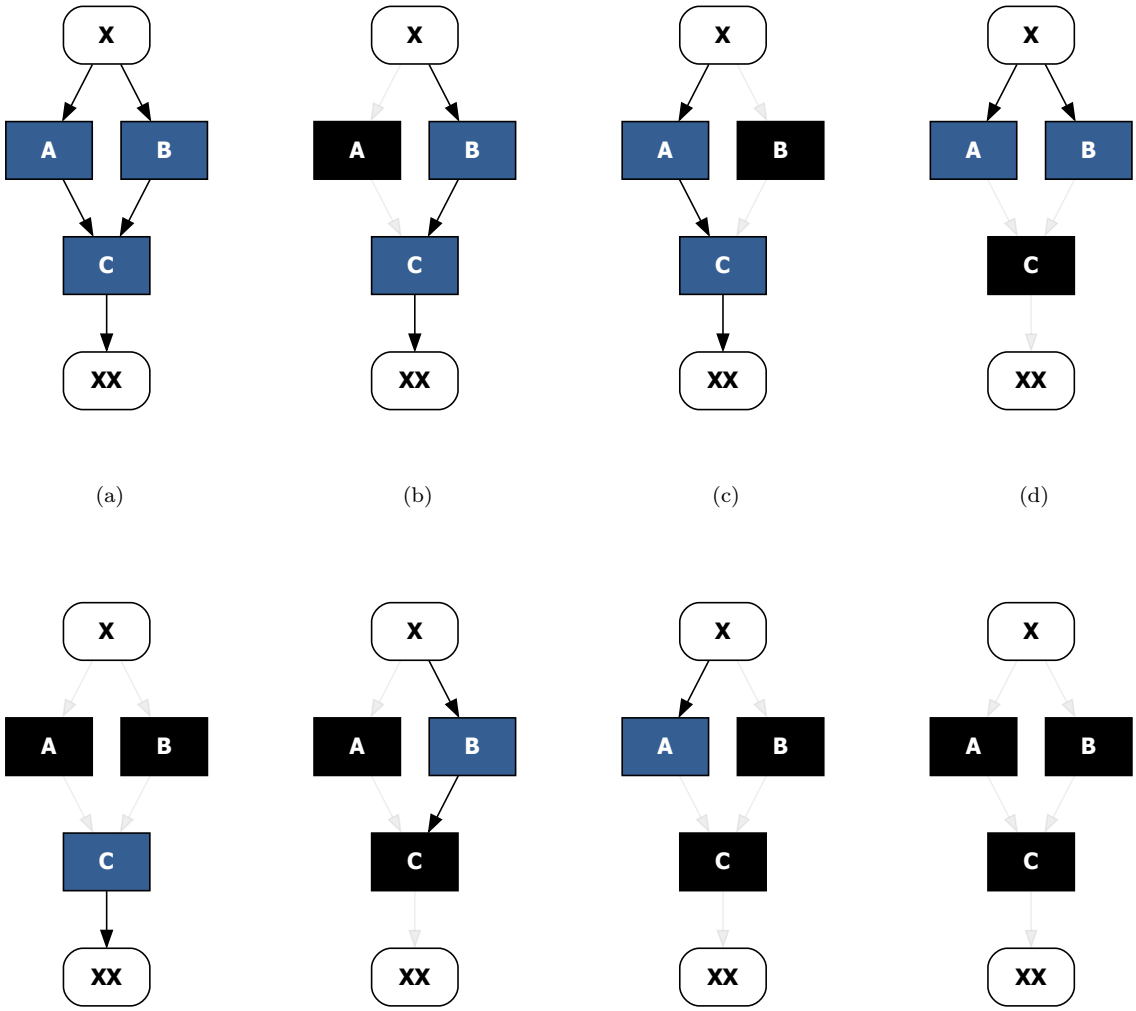


Figure C.4: Graphs of two serial elements in parallel with a third element in various functional states.

Listing C.7: Serial-parallel graphs evaluation (series_parallel.nx.py.txt)

```
import networkx as nx

series_parallel = nx.DiGraph()
series_parallel.add_nodes_from(["X", "XX", "A", "B", "C"])
series_parallel.add_edges_from(
    [("X", "A"), ("X", "B"), ("A", "C"), ("B", "C"), ("C", "XX")]
)

dysf_nodes = [
    [None],
    ["A"],
    ["B"],
    ["C"],
    ["A", "B"],
    ["A", "C"],
    ["B", "C"],
    ["A", "B", "C"],
]

for node_list in dysf_nodes:
    dysf_node_string = str()
    for node in node_list:
        dysf_edges = []
        for edge in series_parallel.edges:
            if node in edge:
                dysf_edges.append(edge)
        for edges in dysf_edges:
            series_parallel.remove_edges_from([edges])
        dysf_node_string = dysf_node_string + f" {node}"
    if nx.has_path(series_parallel, "X", "XX") == True:
        print(
            "A path DOES exist between vertices 'X' and 'XX'"
            + " in the serial-parallel graph with dysfunctional"
            + f" vertices{dysf_node_string}.\n"
        )
    else:
        print(
            "A path DOES NOT exist between vertices 'X' and 'XX'"
            + " in the serial-parallel graph with dysfunctional"
            +f" vertices{dysf_node_string}.\n"
        )
    series_parallel = nx.DiGraph()
    series_parallel.add_nodes_from(["X", "XX", "A", "B", "C"])
    series_parallel.add_edges_from(
        [("X", "A"), ("X", "B"), ("A", "C"), ("B", "C"), ("C", "XX")]
    )
```

Listing C.8: Serial-parallel graphs evaluation output (series_parallel.nx.out)

```
A path DOES exist between vertices 'X' and 'XX' in the serial-parallel graph with dysfunctional vertices
     None.

A path DOES exist between vertices 'X' and 'XX' in the serial-parallel graph with dysfunctional vertices
     A.
```

```

A path DOES exist between vertices 'X' and 'XX' in the serial-parallel graph with dysfunctional vertices
     B.

A path DOES NOT exist between vertices 'X' and 'XX' in the serial-parallel graph with dysfunctional
    vertices C.

A path DOES NOT exist between vertices 'X' and 'XX' in the serial-parallel graph with dysfunctional
    vertices A B.

A path DOES NOT exist between vertices 'X' and 'XX' in the serial-parallel graph with dysfunctional
    vertices A C.

A path DOES NOT exist between vertices 'X' and 'XX' in the serial-parallel graph with dysfunctional
    vertices B C.

A path DOES NOT exist between vertices 'X' and 'XX' in the serial-parallel graph with dysfunctional
    vertices A B C.
```

Appendix D

NuSCAP Python Application

All standard NuSCAP Python packages and computational environment files are provided in the document cited in §D.1. The utility script employed to assign dysfunction threshold values to case study elements is provided here. Exemplar shells of SDF, SOSDF, and ScDF files are given for reference. Likewise, example SNEC input, output, and batch file listings are included.

All file listings are attached to the electronic PDF version of this document.

D.1 Packages

The source code for the NuSCAP packages are available as a controlled-release document [173] to support official government work by contacting the Chief Scientist for Nuclear Weapon Effects at Los Alamos National Laboratory at weapon_effects@lanl.gov.

D.2 Computational Environment Files

Computational environment files required to setup, configure, and execute the NuSCAP application are provided in this section.

D.2.1 Setup

Listing D.1: The NuSCAP setup configuration file (setup.cfg)

```
[bumpversion]
current_version = 0.1.0
commit = True
tag = True

[bumpversion:file:setup.py]
search = version='{current_version}'
replace = version='{new_version}'

[bumpversion:file:NuSCAP/__init__.py]
search = __version__ = '{current_version}'
replace = __version__ = '{new_version}'

[bdist_wheel]
universal = 1

[flake8]
exclude = docs
[tool:pytest]
collect_ignore = ['setup.py']
```

Listing D.2: Python `setuptools` script for the NuSCAP application (setup.py)

```
#!/usr/bin/env python

"""The setup script."""

from setuptools import setup, find_packages

# with open("README.rst") as readme_file:
#     readme = readme_file.read()
#
# with open("HISTORY.rst") as history_file:
#     history = history_file.read()

requirements = []

test_requirements = [
    "pytest>=3",
]

setup(
    author="R. Boone Gilbreath",
    author_email="boone.gilbreath@lanl.gov",
```

```
    python_requires=">=3.6",
    classifiers=[
        "Development Status :: 2 - Pre-Alpha",
        "Intended Audience :: Developers",
        "Natural Language :: English",
        "Programming Language :: Python :: 3",
        "Programming Language :: Python :: 3.6",
        "Programming Language :: Python :: 3.7",
        "Programming Language :: Python :: 3.8",
    ],
    description="TBD",
    install_requires=requirements,
    include_package_data=True,
    keywords="NuSCAP",
    name="NuSCAP",
    packages=find_packages(include=["NuSCAP", "NuSCAP.*"]),
    test_suite="tests",
    tests_require=test_requirements,
    url="https://gitlab.lanl.gov/boone/nuscap",
    version="0.1.0",
    zip_safe=False,
)
```

D.2.2 Requirements

Listing D.3: Python dependencies for running the NuSCAP application (requirements.txt)

```
numpy==1.21.3
matplotlib==3.4.3
pydot==1.4.2
mgrs==1.4.5
networkx==2.8.4
pyproj==3.5.0
graphviz==0.20.1
```

Listing D.4: Python dependencies for developing the NuSCAP application (requirements_dev.txt)

```
pip==21.3.1
bump2version==0.5.11
wheel==0.33.6
watchdog==0.9.0
flake8==3.7.8
tox==3.14.0
coverage==4.5.4
Sphinx>=1.8.5
twine==1.14.0

pytest==6.2.4
black==22.1.0

-r requirements.txt
```

D.2.3 Makefile

Listing D.5: The NuSCAP application makefile (Makefile)

```
.PHONY: clean clean-test clean-pyc clean-build docs help
.DEFAULT_GOAL := help

define BROWSER_PYSCRIPT
import os, webbrowser, sys

from urllib.request import pathname2url

webbrowser.open("file://" + pathname2url(os.path.abspath(sys.argv[1])))
endef
export BROWSER_PYSCRIPT

define PRINT_HELP_PYSCRIPT
import re, sys

for line in sys.stdin:
  match = re.match(r'^([a-zA-Z_-]+):.*?## (.*)$$', line)
  if match:
    target, help = match.groups()
    print("%-20s %s" % (target, help))
endef
export PRINT_HELP_PYSCRIPT

BROWSER := python -c "$$BROWSER_PYSCRIPT"

help:
  @python -c "$$PRINT_HELP_PYSCRIPT" < $(MAKEFILE_LIST)

clean: clean-venv clean-build clean-pyc clean-test ## remove all venv, build, test, coverage and Python
    artifacts

clean-build: ## remove build artifacts
  rm -fr build/
  rm -fr dist/
  rm -fr wheels/
  rm -fr .eggs/
  find . -name '*.egg-info' -exec rm -fr {} +
  find . -name '*.egg' -exec rm -f {} +

clean-pyc: ## remove Python file artifacts
  find . -name '*.pyc' -exec rm -f {} +
  find . -name '*.pyo' -exec rm -f {} +
  find . -name '*~' -exec rm -f {} +
  find . -name '__pycache__' -exec rm -fr {} +

clean-test: ## remove test and coverage artifacts
  rm -fr .tox/
  rm -f .coverage
  rm -fr htmlcov/
  rm -fr .pytest_cache

clean-venv:
  rm -fr bin/*
```

```
  rm -fr include/
  rm -fr lib/
  rm -f pyvenv.cfg

lint/flake8: ## check style with flake8
  flake8 NuSCAP tests
lint/black: ## check style with black
  black --check NuSCAP tests

lint: lint/flake8 lint/black ## check style

test: ## run tests quickly with the default Python
  pytest

test-all: ## run tests on every Python version with tox
  tox

coverage: ## check code coverage quickly with the default Python
  coverage run --source NuSCAP -m pytest
  coverage report -m
  coverage html
  $(BROWSER) htmlcov/index.html

docs: ## generate Sphinx HTML documentation, including API docs
  rm -f docs/NuSCAP.rst
  rm -f docs/modules.rst
  sphinx-apidoc -o docs/ NuSCAP
  $(MAKE) -C docs clean
  $(MAKE) -C docs html
  $(BROWSER) docs/_build/html/index.html

servedocs: docs ## compile the docs watching for changes
  watchmedo shell-command -p '*.rst' -c '$(MAKE) -C docs html' -R -D .

release: dist ## package and upload a release
  twine upload dist/*

dist: clean ## builds source and wheel package
  python setup.py sdist
  python setup.py bdist_wheel
  mkdir wheels
  pip download -r requirements.txt -d wheels
  cp requirements.txt wheels
  echo "pip install -r requirements.txt --no-index --find-links ." > wheels/README.md
  tar czvf wheels.tgz wheels
  mv wheels.tgz dist
  ls -l dist

install: clean ## install the package to the active Python's site-packages
  python setup.py install
```

D.3 Dysfunction Threshold Calculation Script

The simple script used to assign bulk dysfunction threshold values to case study `elements` is provided in the following file listing.

Listing D.6: A script for assigning dysfunction thresholds as a batch (assign_thresholds.py)

```
import numpy as np
import json
import os

personnel_thresholds = {
    "static overpressure": 25,
    "dynamic pressure": "inf",
    "windspeed": "inf",
    "thermal fluence": "inf",
    "total dose": 3000,
    "neutron dose": "inf",
    "neutron fluence": "inf",
    "gamma ray dose": "inf",
    "gamma ray dose rate": "inf",
    "PD": 0.5,
}

electrical_thresholds = {
    "static overpressure": 7,
    "dynamic pressure": 1,
    "windspeed": "inf",
    "thermal fluence": 200,
    "total dose": 1e06,
    "neutron dose": "inf",
    "neutron fluence": 1e12,
    "gamma ray dose": "inf",
    "gamma ray dose rate": 1e10,
    "PD": "inf",
}


mechanical_thresholds = {
    "static overpressure": 20,
    "dynamic pressure": 5,
    "windspeed": "inf",
    "thermal fluence": "inf",
    "total dose": "inf",
    "neutron dose": "inf",
    "neutron fluence": "inf",
    "gamma ray dose": "inf",
    "gamma ray dose rate": "inf",
    "PD": "inf",
}

fiber_optics_thresholds = {
    "static overpressure": 20,
    "dynamic pressure": 5,
    "windspeed": "inf",
```

```
    "thermal fluence": "inf",
    "total dose": 1e03,
    "neutron dose": "inf",
    "neutron fluence": "inf",
    "gamma ray dose": "inf",
    "gamma ray dose rate": "inf",
    "PD": "inf",
}

antenna_thresholds = {
    "static overpressure": 7,
    "dynamic pressure": 1,
    "windspeed": 20,
    "thermal fluence": 200,
    "total dose": 1e06,
    "neutron dose": "inf",
    "neutron fluence": 1e12,
    "gamma ray dose": "inf",
    "gamma ray dose rate": 1e10,
    "PD": "inf",
}

weapon_thresholds = {
    "static overpressure": 20,
    "dynamic pressure": 10,
    "windspeed": 40,
    "thermal fluence": "inf",
    "total dose": "inf",
    "neutron dose": "inf",
    "neutron fluence": "inf",
    "gamma ray dose": "inf",
    "gamma ray dose rate": "inf",
    "PD": "inf",
}

ordnance_thresholds = {
    "static overpressure": 7,
    "dynamic pressure": 2,
    "windspeed": "inf",
    "thermal fluence": 200,
    "total dose": 1e06,
    "neutron dose": "inf",
    "neutron fluence": 1e12,
    "gamma ray dose": "inf",
    "gamma ray dose rate": 1e10,
    "PD": "inf",
}


def random_number():
    rand_num = np.random.normal(1, 0.25)
    if rand_num < 1e-20:
        random_number()
    else:
        random = rand_num
        return random

```

```
def assign_ss(search_dict):

    for _, ss_dict in search_dict.items():

        for env, _ in ss_dict["thresholds"].items():
            ss_dict["thresholds"][env] = "inf"

        random = float(random_number())
        if ss_dict["subtype"] == "personnel":
            ss_dict["VNTK"] = "50I4"
            for key, _ in ss_dict["thresholds"].items():
                if key != "PD":
                    if isinstance(personnel_thresholds[key], float) or isinstance(
                        personnel_thresholds[key], int
                    ):
                        ss_dict["thresholds"][key] = random * personnel_thresholds[key]
        elif ss_dict["subtype"] == "electrical":
            for key, _ in ss_dict["thresholds"].items():
                if isinstance(electrical_thresholds[key], float) or isinstance(
                    electrical_thresholds[key], int
                ):
                    ss_dict["thresholds"][key] = random * electrical_thresholds[key]
        elif ss_dict["subtype"] == "mechanical":
            for key, _ in ss_dict["thresholds"].items():
                if isinstance(mechanical_thresholds[key], float) or isinstance(
                    mechanical_thresholds[key], int
                ):
                    ss_dict["thresholds"][key] = random * mechanical_thresholds[key]
        elif ss_dict["subtype"] == "fiber optics":
            for key, _ in ss_dict["thresholds"].items():
                if isinstance(fiber_optics_thresholds[key], float) or isinstance(
                    fiber_optics_thresholds[key], int
                ):
                    ss_dict["thresholds"][key] = random * fiber_optics_thresholds[key]
        elif ss_dict["subtype"] == "antenna":
            for key, _ in ss_dict["thresholds"].items():
                if isinstance(antenna_thresholds[key], float) or isinstance(
                    antenna_thresholds[key], int
                ):
                    ss_dict["thresholds"][key] = random * antenna_thresholds[key]
        elif ss_dict["subtype"] == "weapon":
            for key, _ in ss_dict["thresholds"].items():
                if isinstance(weapon_thresholds[key], float) or isinstance(
                    weapon_thresholds[key], int
                ):
                    ss_dict["thresholds"][key] = random * weapon_thresholds[key]
        elif ss_dict["subtype"] == "ordnance":
            for key, _ in ss_dict["thresholds"].items():
                if isinstance(ordnance_thresholds[key], float) or isinstance(
                    ordnance_thresholds[key], int
                ):
                    ss_dict["thresholds"][key] = random * ordnance_thresholds[key]
        else:
            pass


```

```python
def find_components(search_dict):

    for _, ss_dict in search_dict.items():
        if isinstance(ss_dict, dict):
            if "Components" in ss_dict.keys():
                for _, data in ss_dict["Components"].items():
                    for env, _ in data["thresholds"].items():
                        data["thresholds"][env] = "inf"
                    random = float(random_number())
                    if data["subtype"] == "personnel":
                        data["VNTK"] = "50I4"
                        for key, _ in data["thresholds"].items():
                            if key != "PD":
                                if isinstance(
                                    personnel_thresholds[key], float
                                ) or isinstance(personnel_thresholds[key], int):
                                    data["thresholds"][key] = (
                                        random * personnel_thresholds[key]
                                    )
                            else:
                                data["thresholds"][key] = 0.50
                    elif data["subtype"] == "electrical":
                        for key, _ in data["thresholds"].items():
                            if isinstance(
                                electrical_thresholds[key], float
                            ) or isinstance(electrical_thresholds[key], int):
                                data["thresholds"][key] = (
                                    random * electrical_thresholds[key]
                                )
                    elif data["subtype"] == "mechanical":
                        for key, _ in data["thresholds"].items():
                            if isinstance(
                                mechanical_thresholds[key], float
                            ) or isinstance(mechanical_thresholds[key], int):
                                data["thresholds"][key] = (
                                    random * mechanical_thresholds[key]
                                )
                    elif data["subtype"] == "fiber optics":
                        for key, _ in data["thresholds"].items():
                            if isinstance(
                                fiber_optics_thresholds[key], float
                            ) or isinstance(fiber_optics_thresholds[key], int):
                                data["thresholds"][key] = (
                                    random * fiber_optics_thresholds[key]
                                )
                    elif data["subtype"] == "antenna":
                        for key, _ in data["thresholds"].items():
                            if isinstance(antenna_thresholds[key], float) or isinstance(
                                antenna_thresholds[key], int
                            ):
                                data["thresholds"][key] = (
                                    random * antenna_thresholds[key]
                                )
                    elif data["subtype"] == "weapon":
                        for key, _ in data["thresholds"].items():
                            if isinstance(weapon_thresholds[key], float) or isinstance(
                                weapon_thresholds[key], int
```

```
                            ):
                                data["thresholds"][key] = (
                                    random * weapon_thresholds[key]
                                )
                    elif data["subtype"] == "ordnance":
                        for key, _ in data["thresholds"].items():
                            if isinstance(
                                ordnance_thresholds[key], float
                            ) or isinstance(ordnance_thresholds[key], int):
                                data["thresholds"][key] = (
                                    random * ordnance_thresholds[key]
                                )
                    else:
                        pass
                find_components(ss_dict)
            else:
                find_components(ss_dict)


def assign_thresholds(path):

    for file in os.listdir(path):

        if str(file).endswith(".sdf.json"):

            with open(os.path.join(path, file), "r", encoding="UTF-8") as SDF:
                data = json.load(SDF)

            subsys_dict = data["Subsystems"]
            sys_dict = data["System"]

            assign_ss(sys_dict)
            assign_ss(subsys_dict)
            find_components(subsys_dict)

            out = json.dumps(data, indent=4)
            with open(os.path.join(path, file), "w", encoding="UTF-8") as outfile:
                outfile.write(out)


assign_thresholds(
    "C:\\Users\\339528\\Documents\\Git\\NuSCAP\\Users\\Gilbreath\\Systems\\"
)
```

D.4 Data File Shells

Example data file shells for system data files (SDF), system-of-system data files (SOSDF), and scenario data files (ScDF) are provided in this section. Consult §4.1.2 for guidance on editing and using these file types.

D.4.1 System Data File

Listing D.7: An example system data file shell (Example.sdf.json)

```
{
    "HEADER COMMENTS": "Administrative comments about the system in question",
    "System": {
        "This_System_Name": {
            "ID": "Secondary System Identifier",
            "type": "equipment",
            "subtype": "mechanical",
            "VNTK": "50I1",
            "thresholds": {
                "static overpressure": 3.1,
                "dynamic pressure": "inf",
                "windspeed": 80,
                "thermal fluence": 15,
                "total dose": 1000,
                "neutron dose": 400,
                "neutron fluence": 1e10,
                "gamma ray dose": 600,
                "gamma ray dose rate": 1e12,
                "PD": 0.51
            }
        }
    },
    "Subsystems": {
        "Subsystem_1_Name": {
            "ID": "Secondary Subsystem 1 Identifier",
            "type": <str_type>,
            "subtype": <str_subtype>,
            "relative position":[2.75,-3.25,0.875],
            "VNTK": <str_VNTK>,
            "thresholds": {
                "static overpressure": <a_number>,
                "dynamic pressure": <a_number>,
                "windspeed": <a_number>,
                "thermal fluence": <a_number>,
                "total dose": <a_number>,
                "neutron dose": <a_number>,
                "neutron fluence": <a_number>,
                "gamma ray dose": <a_number>,
                "gamma ray dose rate": <a_number>,
                "PD": <a_number>
            },
            "Components": {
                "Component_1_of_Subsystem_1_Name": {
```

```
                    "ID": "Secondary Component 1.1 Identifier",
                    "type": "human",
                    "subtype": "personnel",
                    "relative position":[<x_num>,<y_num>,<z_num>],
                    "VNTK": <str_VNTK>,
                    "thresholds": {
                        "static overpressure": <a_number>,
                        "dynamic pressure": <a_number>,
                        "windspeed": <a_number>,
                        "thermal fluence": <a_number>,
                        "total dose": <a_number>,
                        "neutron dose": <a_number>,
                        "neutron fluence": <a_number>,
                        "gamma ray dose": <a_number>,
                        "gamma ray dose rate": <a_number>,
                        "PD": <a_number>
                    }
                },
                "Component_2_of_Subsystem_1_Name": {
                    "ID": "Secondary Component 1.2 Identifier",
                    "type": <str_type>,
                    "subtype": <str_subtype>,
                    "relative position":[<x_num>,<y_num>,<z_num>],
                    "VNTK": <str_VNTK>,
                    "thresholds": {
                        "static overpressure": <a_number>,
                        "dynamic pressure": <a_number>,
                        "windspeed": <a_number>,
                        "thermal fluence": <a_number>,
                        "total dose": <a_number>,
                        "neutron dose": <a_number>,
                        "neutron fluence": <a_number>,
                        "gamma ray dose": <a_number>,
                        "gamma ray dose rate": <a_number>,
                        "PD": <a_number>
                    },
                    "Components": {
                        "Subcomponent_1_of_Component_1_Name": {
                            "ID": "Secondary Subcomponent 1.2.1 Identifier",
                            "type": <str_type>,
                            "subtype": <str_subtype>,
                            "relative position":[<x_num>,<y_num>,<z_num>],
                            "VNTK": <str_VNTK>,
                            "thresholds": {
                                "static overpressure": <a_number>,
                                "dynamic pressure": <a_number>,
                                "windspeed": <a_number>,
                                "thermal fluence": <a_number>,
                                "total dose": <a_number>,
                                "neutron dose": <a_number>,
                                "neutron fluence": <a_number>,
                                "gamma ray dose": <a_number>,
                                "gamma ray dose rate": <a_number>,
                                "PD": <a_number>
                            },
                            "Components": {
                                "Subcomponent_1_of_Subcomponent_1_Name": {
```

```
                                    "ID": "Secondary Subcomponent 1.2.1.1 Identifier",
                                    "type": <str_type>,
                                    "subtype": <str_subtype>,
                                    "relative position":[<x_num>,<y_num>,<z_num>],
                                    "VNTK": <str_VNTK>,
                                    "thresholds": {
                                        "static overpressure": <a_number>,
                                        "dynamic pressure": <a_number>,
                                        "windspeed": <a_number>,
                                        "thermal fluence": <a_number>,
                                        "total dose": <a_number>,
                                        "neutron dose": <a_number>,
                                        "neutron fluence": <a_number>,
                                        "gamma ray dose": <a_number>,
                                        "gamma ray dose rate": <a_number>,
                                        "PD": <a_number>
                                    }
                                }
                            }
                        }
                    }
                },
                "Component_n_of_Subsystem_1_Name": {
                    "ID": "Secondary Component 1.n Identifier",
                    "type": <str_type>,
                    "subtype": <str_subtype>,
                    "relative position":[<x_num>,<y_num>,<z_num>],
                    "VNTK": <str_VNTK>,
                    "thresholds": {
                        "static overpressure": <a_number>,
                        "dynamic pressure": <a_number>,
                        "windspeed": <a_number>,
                        "thermal fluence": <a_number>,
                        "total dose": <a_number>,
                        "neutron dose": <a_number>,
                        "neutron fluence": <a_number>,
                        "gamma ray dose": <a_number>,
                        "gamma ray dose rate": <a_number>,
                        "PD": <a_number>
                    }
                }
            },
        "Subsystem_2_Name": {
            "ID": "Secondary Subsystem 1 Identifier",
            "type": <str_type>,
            "subtype": <str_subtype>,
            "relative position":[<x_num>,<y_num>,<z_num>],
            "VNTK": <str_VNTK>,
            "thresholds": {
                "static overpressure": 1,
                "dynamic pressure": <a_number>,
                "windspeed": <a_number>,
                "thermal fluence": <a_number>,
                "total dose": <a_number>,
                "neutron dose": <a_number>,
                "neutron fluence": <a_number>,
```

```
                "gamma ray dose": <a_number>,
                "gamma ray dose rate": <a_number>,
                "PD": <a_number>
            },
            "Components": {
                "Component_1_of_Subsystem_2_Name": {
                    "ID": "Secondary Component 2.1 Identifier",
                    "type": <str_type>,
                    "subtype": <str_subtype>,
                    "relative position":[<x_num>,<y_num>,<z_num>],
                    "VNTK": <str_VNTK>,
                    "thresholds": {
                        "static overpressure": <a_number>,
                        "dynamic pressure": <a_number>,
                        "windspeed": <a_number>,
                        "thermal fluence": <a_number>,
                        "total dose": <a_number>,
                        "neutron dose": <a_number>,
                        "neutron fluence": <a_number>,
                        "gamma ray dose": <a_number>,
                        "gamma ray dose rate": <a_number>,
                        "PD": <a_number>
                    }
                },
                "Component_2_of_Subsystem_2_Name": {
                    "ID": "Secondary Component 2.2 Identifier",
                    "type": <str_type>,
                    "subtype": <str_subtype>,
                    "relative position":[<x_num>,<y_num>,<z_num>],
                    "VNTK": <str_VNTK>,
                    "thresholds": {
                        "static overpressure": <a_number>,
                        "dynamic pressure": <a_number>,
                        "windspeed": <a_number>,
                        "thermal fluence": <a_number>,
                        "total dose": <a_number>,
                        "neutron dose": <a_number>,
                        "neutron fluence": <a_number>,
                        "gamma ray dose": <a_number>,
                        "gamma ray dose rate": <a_number>,
                        "PD": <a_number>
                    },
                    "Components": {
                        "Subcomponent_1_of_Component_2_Name": {
                            "ID": "Secondary Subcomponent 2.2.1 Identifier",
                            "type": <str_type>,
                            "subtype": <str_subtype>,
                            "relative position":[<x_num>,<y_num>,<z_num>],
                            "VNTK": <str_VNTK>,
                            "thresholds": {
                                "static overpressure": <a_number>,
                                "dynamic pressure": <a_number>,
                                "windspeed": <a_number>,
                                "thermal fluence": <a_number>,
                                "total dose": <a_number>,
                                "neutron dose": <a_number>,
                                "neutron fluence": <a_number>,
```

```
                                "gamma ray dose": <a_number>,
                                "gamma ray dose rate": <a_number>,
                                "PD": <a_number>
                            }
        }
                    }
                },
                "Component_n_of_Subsystem_2_Name": {
                    "ID": "Secondary Component 2.n Identifier",
                    "type": <str_type>,
                    "subtype": <str_subtype>,
                    "relative position":[<x_num>,<y_num>,<z_num>],
                    "VNTK": <str_VNTK>,
                    "thresholds": {
                        "static overpressure": <a_number>,
                        "dynamic pressure": <a_number>,
                        "windspeed": <a_number>,
                        "thermal fluence": <a_number>,
                        "total dose": <a_number>,
                        "neutron dose": <a_number>,
                        "neutron fluence": <a_number>,
                        "gamma ray dose": <a_number>,
                        "gamma ray dose rate": <a_number>,
                        "PD": <a_number>
                    }
                }
            }
        },
        "Subsystem_n_Name": {
            "ID": "Subsystem n Secondary Identifier",
            "type": <str_type>,
            "subtype": <str_subtype>,
            "relative position":[<x_num>,<y_num>,<z_num>],
            "VNTK": <str_VNTK>,
            "thresholds": {
                "static overpressure": <a_number>,
                "dynamic pressure": <a_number>,
                "windspeed": <a_number>,
                "thermal fluence": <a_number>,
                "total dose": <a_number>,
                "neutron dose": <a_number>,
                "neutron fluence": <a_number>,
                "gamma ray dose": <a_number>,
                "gamma ray dose rate": <a_number>,
                "PD": <a_number>
            }
        }
    },
    "capabilities": {
        "First Capability": [
            {
                "Most Capable Bin": {
                    "Begin Node": ["X"],
                    "End Node": ["FF"],
                    "Has Path": [true],
                    "Comment": "Description of capability bin"
                }
```

```
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": ["X"],
                    "End Node": ["FF"],
                    "Has Path": [false],
                    "Comment": "Capability is not possible"
                }
            },
            {
                "Degraded Capability Bin 1": {
                    "Begin Node": ["AA", "BB"],
                    "End Node": ["DD", "EE"],
                    "Has Path": [false, true],
                    "Comment": "Description of degraded state 1"
                }
            },
            {
                "Degraded Capability Bin 2": {
                    "Begin Node": ["AA", "BB"],
                    "End Node": ["DD", "EE"],
                    "Has Path": [true, false],
                    "Comment": "Description of degraded state 2"
                }
            }
        ],
        "Next Capability": [
            {
                "Most Capable Bin": {
                    "Begin Node": ["BB"],
                    "End Node": ["EE"],
                    "Has Path": [true],
                    "Comment": "Description of capabilty bin"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": ["BB"],
                    "End Node": ["EE"],
                    "Has Path": [false],
                    "Comment": "Capability is not possible"
                }
            },
            {
                "Degraded Capability Bin": {
                    "Begin Node": ["BB"],
                    "End Node": ["Component_n_of_Subsystem_2_Name"],
                    "Has Path": [true],
                    "Comment": "Description of degraded state"
                }
            }
        ]
    },
    "Structure": {
        "Admin Nodes": ["AA", "BB", "CC", "DD", "EE", "FF"],
        "Terminal Nodes": ["X", "XX"],
        "Edges": {
```

```
            "X": ["This_System_Name"],
            "This_System_Name": ["Subsystem_1_Name", "Subsystem_2_Name", "Subsystem_n_Name"],
      "Subsystem_1_Name":["AA"],
      "AA":["Component_1_of_Subsystem_1_Name", "Component_2_of_Subsystem_1_Name"],
      "Component_1_of_Subsystem_1_Name":["Subcomponent_1_of_Component_1_Name"],
      "Subcomponent_1_of_Component_1_Name":["Subcomponent_1_of_Subcomponent_1_Name"],
      "Component_2_of_Subsystem_1_Name":["Component_n_of_Subsystem_1_Name"],
      "Component_n_of_Subsystem_1_Name":["DD"],
      "Subcomponent_1_of_Subcomponent_1_Name":["DD"],
      "Subsystem_2_Name":["BB"],
      "BB":["Component_1_of_Subsystem_2_Name", "Component_2_of_Subsystem_2_Name"],
      "Component_1_of_Subsystem_2_Name":["Component_n_of_Subsystem_2_Name"],
      "Component_2_of_Subsystem_2_Name":["Subcomponent_1_of_Component_2_Name"],
      "Component_n_of_Subsystem_2_Name":["EE"],
      "Subcomponent_1_of_Component_2_Name":["EE"],
      "Subsystem_n_Name":["CC"],
      "CC":["XX"],
      "DD":["FF"],
      "EE":["FF"],
      "FF":["XX"]

        }
    },
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",

    "Maintainer": "C. C. Carter",
    "Maintainer Title": "Analyst",
    "Maintainer Organization": "NuSCAP, LLC"
}
```

D.4.2 System of System Data File

Listing D.8: An example system-of-systems data file shell (Example.sosdf.json)

```
{
    "HEADER COMMENTS": "Comments about the SOS being studied",
    "System of Systems": {
        "Your_SOS_Name": {
    "ID": "Secondary identifier for the SOS"
  }
    },
    "Systems": {
        "System_1_Name": {"SDF Path": "~\\NuSCAP\\Users\\Your_User_Name\\Systems\\System_1_Data_File.sdf.
    json"},
        "System_2_Name": {"SDF Path": "~\\NuSCAP\\Users\\Your_User_Name\\Systems\\System_2_Data_File.sdf.
    json"},
        "System_n_Name": {"SDF Path": "~\\NuSCAP\\Users\\Your_User_Name\\Systems\\System_n_Data_File.sdf.
    json"}
    },
    "SOS capabilities": {
        "Capability 1 Name": [
            {
                "Most Capable Bin": {
                    "Begin Node": ["X", "X"],
                    "End Node": ["DD1", "CC2"],
                    "Has Path": [true, true],
                    "Comment": "Description of capability bin"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": ["X", "X"],
                    "End Node": ["DD1", "CC2"],
                    "Has Path": [false, false],
                    "Comment": "Capability is not possible"
                }
            },
            {
                "First Degraded State Bin": {
                    "Begin Node": ["X", "X"],
                    "End Node": ["DD1", "CC2"],
                    "Has Path": [false, true],
                    "Comment": "Description of degraded state 1"
                }
            },
            {
                "Second Degraded State Bin": {
                    "Begin Node": ["X", "X"],
                    "End Node": ["DD1", "CC2"],
                    "Has Path": [true, false],
                    "Comment": "Description of degraded state 2"
                }
            }
        ],
        "Capability 2 Name": [
            {
                "Most Capable Bin": {
```

```
                    "Begin Node": ["X", "DD1", "BB3", "DD1", "EE1" ],
                    "End Node": ["DD1", "BB3", "EE31", "EE1"," EE3"],
                    "Has Path": [true, true, true, true, true],
                    "Comment": "Description of capability bin"
                }
            },
            {
                "NOT POSSIBLE 1": {
                    "Begin Node": ["X3"],
                    "End Node": ["EE31"],
                    "Has Path": [false],
                    "Comment": "Capability is not possible (instance 1)"
                }
            },
            {
                "NOT POSSIBLE 2": {
                    "Begin Node": ["FF1", "X_3"],
                    "End Node": ["EE31", "AA_3"],
                    "Has Path": [false, true],
                    "Comment": "Capability is not possible (instance 2)"
                }
            },
            {
                "First Degraded State Bin": {
                    "Begin Node": ["X3", "FF1", "FF1"],
                    "End Node": ["DD1", "EE31", "EE3"],
                    "Has Path": [true, true, false],
                    "Comment": "Description of degraded state 1"
                }
            },
            {
                "n-th Degraded State Bin": {
                    "Begin Node": ["X3", "FF1", "FF1"],
                    "End Node": ["DD1", "EE31", "EE3"],
                    "Has Path": [true, false, true],
                    "Comment": "Description of degraded state n"
                }
            }
        ],
        "Capability n Name": [
            {
                "Most Capable Bin": {
                    "Begin Node": ["X3", "X3", "X2", "X2", "X2"],
                    "End Node": ["CC2", "DD1", "KK2", "LL2","HH1"],
                    "Has Path": [true, true, true, true, true],
                    "Comment": "Description of Bin 1"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": ["X3"],
                    "End Node": ["CC2"],
                    "Has Path": [false],
                    "Comment": "Capability is not possible"
                }
            },
            {
```

```
                "Degraded State Bin": {
                    "Begin Node": ["X3", "X3", "X2", "X2", "X2"],
                    "End Node": ["CC2", "DD1", "KK2", "LL2","HH1"],
                    "Has Path": [true, true, true, false, true],
                    "Comment": "Description of degraded state"
                }
            }
        ]
    },
    "SOS Structure": {
        "Admin Nodes": [],
        "Terminal Nodes": ["X", "XX"],
        "Edges": {
            "X": ["X3"],
            "XX51": ["XX"],
            "XX52": ["XX"],
            "XX53": ["XX"],
            "XX54": ["XX"],
            "XX55": ["XX"],
            "XX56": ["XX"]
        },
        "Capability Edges": {
            "X": ["X_3"],
            "DD3": ["X1"],
            "CC3": ["X2"],
            "EE1": ["BB3"],
            "EE11": ["BB3"],
            "HH2": ["EE11"],
            "JJ1b": ["X51","X52","X53","X54","X55","X56"],
            "JJ11a": ["X51"],
            "JJ12a": ["X52"],
            "JJ13a": ["X53"],
            "JJ14a": ["X54"],
            "JJ15a": ["X55"],
            "JJ16a": ["X56"]
        }
    },
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",

    "Maintainer": "A. M. Gamble",
    "Maintainer Title": "Analyst",
    "Maintainer Organization": "NuSCAP, LLC"
}
```

D.4.3 Analytical Scenario Data File

Listing D.9: An example analytical scenario data file shell (Example.scdf.json)

```
{
    "HEADER COMMENTS":"Description of the scenario being studied",
  "Prefix":"~\\NuSCAP\\Users\\Your_User_Name\\Your_Working_Directory",
  "Name":"Your_Scenario_Name",
    "MCNP path":"C:\\MCNP62\\MCNP_CODE\\bin\\mcnp6",
    "MCNP datapath":"C:\\MCNP62\\MCNP_DATA",
    "MCNP threads":8,
    "SNEC path":"C:\\Users\\339528\\Documents\\Git\\NuSCAP\\NuSCAP\\JSL\\JSL_5.6\\Dist_2\\Combined_JSL_5
     .6_Distro\\Java Tools for Windows\\WebMultipleEffects",
    "GIS and Weather Data":{
        "GIS Reference Datum": "WGS84",
        "Ground Zero Location": "13S CT 63233 27353",
        "Ground Zero Elevation (MSL) [m]": 1501,
        "DTG":"16 0530T JUL 1945",
        "Atmospheric Visibility [km]": 50
    },
    "Threat Weapon Data":{
        "Weapon Type":"Fission",
        "Fission Fraction": 1,
        "Yield [kt]": 24.8,
        "HOB [m]": 30.48,
        "HOB sigma [m]":0,
        "CEP [m]": 0,
        "NPS":1E9,
        "Neutron Leakage Spectrum":{
            "neutron yield [mol/kt]": 0.264,
            "si option":"H",
            "energy bins [MeV]":[
                1.00E-16, 1.00E-11, 5.00E-10, 2.00E-9, 5.00E-9, 1.00E-8, 1.45E-8, 2.10E-8,
                3.00E-8, 4.00E-8, 5.00E-8, 7.00E-8, 1.00E-7, 1.25E-7, 1.50E-7, 1.84E-7,
                2.25E-7, 2.75E-7, 3.25E-7, 3.67E-7, 4.14E-7, 5.00E-7, 5.32E-7, 6.25E-7,
                6.83E-7, 8.00E-7, 8.67E-7, 1.00E-6, 1.04E-6, 1.08E-6, 1.13E-6, 1.30E-6,
                1.45E-6, 1.86E-6, 2.38E-6, 3.06E-6, 3.93E-6, 5.04E-6, 6.48E-6, 8.32E-6,
                1.07E-5, 1.37E-5, 1.76E-5, 2.26E-5, 2.90E-5, 3.73E-5, 4.79E-5, 6.14E-5,
                7.89E-5, 1.01E-4, 1.30E-4, 1.67E-4, 2.14E-4, 2.75E-4, 3.54E-4, 4.54E-4,
                5.83E-4, 7.49E-4, 9.61E-4, 1.23E-3, 1.58E-3, 2.03E-3, 2.25E-3, 2.49E-3,
                2.61E-3, 2.75E-3, 3.04E-3, 3.35E-3, 3.71E-3, 4.31E-3, 5.53E-3, 7.10E-3,
                9.12E-3, 1.06E-2, 1.17E-2, 1.50E-2, 1.93E-2, 2.19E-2, 2.36E-2, 2.42E-2,
                2.48E-2, 2.61E-2, 2.70E-2, 2.85E-2, 3.18E-2, 3.43E-2, 4.09E-2, 4.63E-2,
                5.25E-2, 5.66E-2, 6.74E-2, 7.20E-2, 7.95E-2, 8.25E-2, 8.65E-2, 9.80E-2,
                1.11E-1, 1.17E-1, 1.23E-1, 1.29E-1, 1.36E-1, 1.43E-1, 1.50E-1, 1.58E-1,
                1.66E-1, 1.74E-1, 1.83E-1, 1.93E-1, 2.02E-1, 2.13E-1, 2.24E-1, 2.35E-1,
                2.47E-1, 2.73E-1, 2.87E-1, 2.95E-1, 2.97E-1, 2.98E-1, 3.02E-1, 3.34E-1,
                3.69E-1, 3.88E-1, 4.08E-1, 4.50E-1, 4.98E-1, 5.23E-1, 5.50E-1, 5.78E-1,
                6.08E-1, 6.39E-1, 6.72E-1, 7.07E-1, 7.43E-1, 7.81E-1, 8.21E-1, 8.63E-1,
                9.07E-1, 9.62E-1, 1.00, 1.11, 1.16, 1.22, 1.29, 1.35, 1.42, 1.50, 1.57,
                1.65, 1.74, 1.83, 1.92, 2.02, 2.12, 2.23, 2.31, 2.35, 2.37, 2.39, 2.47,
                2.59, 2.73, 2.87, 3.01, 3.17, 3.33, 3.68, 4.07, 4.49, 4.72, 4.97, 5.23,
                5.49, 5.77, 6.07, 6.38, 6.59, 6.70, 7.05, 7.41, 7.79, 8.19, 8.61, 9.05,
                9.51, 10.0, 10.5, 11.1, 11.6, 12.2, 12.5, 12.8, 13.5, 13.8, 14.2, 14.6,
                14.9, 15.7, 16.5, 16.9, 17.3, 20.0
            ],
            "sp option":"D",
```

```
            "probability [mol/MeV-kt]":[
                0, 1.00E-9, 2.04E-11, 6.67E-12, 3.33E-12, 2.00E-12, 2.22E-12, 1.78, 2.75, 3.07,
                5.95, 12.7, 15.5, 22.8, 31.9, 23.9, 46.0, 44.1, 59.2, 75.7, 64.2, 80.9, 99.7,
                1.00E2, 111, 139, 159, 170, 174, 197, 182, 218, 235, 271, 339, 410, 512, 616,
                748, 886, 1.04E3, 1.19E3, 1.34E3, 1.45E3, 1.52E3, 1.54E3, 1.48E3, 1.36E3,
                1.19E3, 996, 794, 614, 462, 334, 228, 141, 74.8, 33.3, 12.4, 3.84, 1.02,
                2.26E-1, 7.77E-2, 6.15E-2, 4.43E-2, 3.12E-2, 3.34E-2, 2.52E-2, 2.17E-2, 1.67E-2,
                1.40E-2, 1.08E-2, 8.59E-3, 6.76E-3, 5.36E-3, 5.23E-3, 4.57E-3, 4.19E-3, 4.43E-3,
                4.53E-3, 4.36E-3, 4.87E-3, 4.89E-3, 1.20E-3, 1.42E-3, 1.31E-3, 1.13E-3, 1.92E-3,
                1.76E-3, 1.65E-3, 1.79E-3, 2.17E-3, 1.70E-3, 1.30E-3, 5.97E-4, 8.85E-4, 1.16E-3,
                1.33E-3, 1.01E-3, 1.55E-3, 1.44E-3, 8.63E-4, 6.13E-4, 7.12E-4, 8.11E-4, 9.41E-4,
                1.04E-3, 9.16E-4, 7.07E-4, 6.42E-4, 7.43E-4, 7.87E-4, 8.82E-4, 9.11E-4, 7.03E-4,
                7.30E-4, 8.21E-4, 6.02E-4, 7.36E-4, 6.93E-4, 7.46E-4, 6.05E-4, 6.61E-4, 4.35E-4,
                6.21E-4, 6.59E-4, 6.69E-4, 6.71E-4, 7.90E-4, 7.04E-4, 6.70E-4, 6.48E-4, 6.64E-4,
                6.06E-4, 5.40E-4, 5.52E-4, 4.98E-4, 4.85E-4, 3.69E-4, 3.88E-4, 4.68E-4, 4.65E-4,
                4.67E-4, 3.91E-4, 4.46E-4, 4.48E-4, 4.17E-4, 3.76E-4, 4.15E-4, 3.74E-4, 3.37E-4,
                3.39E-4, 3.51E-4, 3.54E-4, 3.70E-4, 4.51E-4, 4.31E-4, 4.45E-4, 3.63E-4, 2.79E-4,
                2.60E-4, 2.27E-4, 1.84E-4, 1.83E-4, 1.16E-4, 9.70E-5, 9.33E-5, 8.52E-5, 1.00E-4,
                9.49E-5, 7.73E-5, 6.52E-5, 5.32E-5, 5.05E-5, 3.92E-5, 3.45E-5, 3.18E-5, 3.03E-5,
                1.79E-5, 1.26E-5, 9.18E-6, 1.02E-5, 6.88E-6, 5.81E-6, 3.17E-6, 2.07E-6, 1.75E-6,
                1.29E-6, 9.17E-7, 3.68E-7, 4.17E-7, 1.96E-7, 8.11E-8, 2.01E-7, 1.63E-7, 2.43E-7,
                1.05E-7, 3.11E-8, 6.58E-8, 0, 2.86E-8
            ],
            "reference":"R. Holmes and S. White, 'Output of Fat Man and Little Boy Devices,' Los Alamos
    National Laboratory, LA-UR-13-26113, Aug. 2103; Tables 2 & 6"
        },
        "Neutron Response Functions":{
            "Human":{
                "Energy [MeV]":[
                    2.5E-8, 1.0E-7, 1.0E-6, 1.0E-5, 1.0E-4, 1.0E-3, 0.01, 0.1, 0.5, 1.0, 2.5, 5.0,
                    7.0, 10.0, 14.0, 20.0
                ],
                "Conversion Factor":{
                    "units":"[(rem/hr)/(cm$^{-2}\\cdot$s$^{-1}$)]",
                    "values":
                    [
                    3.67E-6, 3.67E-6, 4.46E-6, 4.54E-6, 4.18E-6, 3.76E-6, 3.56E-6, 2.17E-5, 9.26E-5,
                    1.32E-4, 1.25E-4, 1.56E-4, 1.47E-4, 1.47E-4, 2.08E-4, 2.27E-4
                    ]
                    },
                "Quality Factor":[
                    2.0, 2.0, 2.0, 2.0, 2.0, 2.0, 2.5, 7.5, 11.0, 11.0, 9.0, 8.0, 7.0, 6.5, 7.5, 8.0
                ],
                "reference":"J. Kulesza, et al., 'MCNP Code Version 6.3.0 Theory & User Manual,' Los
    Alamos National Laboratory, Los Alamos, NM, USA, Tech. Rep. LA-UR-22-30006, Rev. 1, Sep. 2022. ANSI/
    ANS-6.1.1-1977, Table 1"
            },
            "Equipment":{
                "Fluence":{
                    "Energy [MeV]":[
                        1.38880E-10, 1.00000E-09, 5.00000E-09, 1.00000E-08, 3.00000E-08, 7.00000E-08,
                        1.00000E-07, 1.52300E-07, 2.00000E-07, 4.13990E-07, 6.00000E-07, 8.00000E-07,
                        1.12530E-06, 3.05900E-06, 5.04350E-06, 8.31530E-06, 1.37100E-05, 2.26030E-05,
                        3.72660E-05, 6.14420E-05, 1.01300E-04, 1.67020E-04, 2.75360E-04, 3.53580E-04,
                        4.54000E-04, 5.82950E-04, 7.48520E-04, 9.61120E-04, 1.08910E-03, 1.23410E-03,
                        1.39840E-03, 1.58460E-03, 1.79560E-03, 2.03470E-03, 2.30560E-03, 2.61260E-03,
                        2.96040E-03, 3.35460E-03, 3.80130E-03, 4.30740E-03, 4.88100E-03, 5.53080E-03,
```

```
                        6.26730E-03, 7.10170E-03, 8.04730E-03, 9.11880E-03, 1.03330E-02, 1.17090E-02,
                        1.32680E-02, 1.50340E-02, 1.70360E-02, 1.93040E-02, 2.18750E-02, 2.47880E-02,
                        2.60580E-02, 2.80880E-02, 3.18280E-02, 4.08680E-02, 5.24750E-02, 6.73790E-02,
                        8.65170E-02, 1.11090E-01, 1.42640E-01, 1.83160E-01, 2.35180E-01, 3.01970E-01,
                        3.87740E-01, 4.39370E-01, 4.97870E-01, 5.64160E-01, 6.39280E-01, 7.24400E-01,
                        8.20850E-01, 9.30140E-01, 1.05400E00, 1.19430E00, 1.35340E00, 1.73770E00,
                        2.23130E00, 2.86510E00, 3.67880E00, 4.72370E00, 6.06530E00, 7.78800E00,
                        1.00000E01, 1.19120E01, 1.34990E01, 1.49180E01, 1.69050E01, 2.00000E01
                    ],
                    "Conversion Factor":{
                        "units":"1-MeV neutron Equivalent Fluence",
                        "values":
                        [
                        0.000000, 7.38697E-03, 3.13312E-03, 1.87815E-03, 1.17364E-03, 7.32402E-04,
                        5.52298E-04, 4.53680E-04, 3.83152E-04, 2.93933E-04, 2.26408E-04, 1.92229E-04,
                        1.64111E-04, 1.14214E-04, 8.03363E-05, 6.25425E-05, 4.87135E-05, 3.79357E-05,
                        2.95522E-05, 2.30102E-05, 1.79240E-05, 1.39594E-05, 3.00309E-04, 5.55850E-04,
                        6.65494E-04, 7.68969E-04, 9.10440E-04, 1.10621E-03, 1.29490E-03, 1.44634E-03,
                        1.60935E-03, 1.80074E-03, 2.01916E-03, 2.27304E-03, 3.26010E-03, 2.87101E-03,
                        3.21528E-03, 3.61954E-03, 4.06547E-03, 4.58726E-03, 5.22228E-03, 5.83754E-03,
                        6.49984E-03, 7.30252E-03, 8.18355E-03, 9.18417E-03, 1.02944E-02, 1.15055E-02,
                        1.28715E-02, 1.43322E-02, 1.63567E-02, 1.77608E-02, 1.96045E-02, 2.16808E-02,
                        2.30574E-02, 2.40674E-02, 2.58766E-02, 2.95862E-02, 2.53388E-02, 1.44824E-01,
                        6.03347E-02, 4.99138E-02, 2.51383E-02, 3.30996E-01, 9.39793E-01, 5.87161E-01,
                        5.27088E-01, 5.51634E-01, 5.74569E-01, 8.18293E-01, 6.84671E-01, 5.99507E-01,
                        9.58147E-01, 1.02449E+00, 1.02066E+00, 7.14611E-01, 9.53149E-01, 1.23834E+00,
                        1.18819E+00, 1.24346E+00, 1.21600E+00, 1.44917E+00, 1.66224E+00, 1.69987E+00,
                        1.80733E+00, 1.79803E+00, 1.88335E+00, 1.88105E+00, 1.94630E+00, 2.04731E+00
                        ]
                    },
                    "reference":"K. R. DePriest, 'Silicon Damage Response Function Derivation and
    Verification: Assessment of Impact on ASTM Standard E722,' Sandia National Laboratories, SAND2016
    -5511, Jun. 2016; Appendix B"
                },
                "Dose":{
                "units":"[rad (Si)]",
                "values":"3.3450364E-10  3  -4  1",
                "reference":"MatMCNP, K. R. DePriest"
      }
        }
        },
        "Photon Leakage Spectrum":{
            "photon yield [mol/kt]":9.02E-2,
            "si option":"H",
            "energy bins [MeV]":[
                0.001, 0.010, 0.020, 0.030, 0.040, 0.045, 0.060, 0.070, 0.075, 0.100, 0.150,
                0.200, 0.300, 0.400, 0.450, 0.510, 0.512, 0.600, 0.700, 0.800, 1.000, 1.330,
                1.340, 1.500, 1.660, 2.000, 2.500, 3.000, 3.500, 4.000, 4.500, 5.000, 5.500,
                6.000, 6.500, 7.000, 7.500, 8.000, 10.000, 12.000, 14.000, 20.000, 30.000
            ],
            "sp option":"D",
            "probability [mol/MeV-kt]":[
                0, 4.43E-4, 8.51E-4, 7.53E-4, 1.39E-3, 2.25E-3, 5.86E-3, 1.72E-2, 2.38E-2,
                5.85E-2, 8.00E-2, 7.46E-2, 7.76E-2, 5.83E-2, 5.48E-2, 6.76E-2, 3.85E-1, 7.32E-2,
                4.00E-2, 3.35E-2, 3.08E-2, 2.34E-2, 1.90E-2, 2.07E-2, 1.84E-2, 1.66E-2, 1.59E-2,
                7.66E-3, 4.25E-3, 5.43E-3, 2.58E-3, 6.75E-4, 5.44E-4, 4.29E-4, 3.55E-4, 3.50E-4,
                1.20E-4, 9.42E-4, 2.79E-5, 9.69E-6, 3.38E-8, 1.67E-13, 0
```

```
            ],
            "reference":"R. Holmes and S. White, 'Output of Fat Man and Little Boy Devices,' Los Alamos National Laboratory, LA-UR-13-26113, Aug. 2103; Tables 2 & 7"
        },
        "Photon Response Functions":{
            "Human":{
            "Energy [MeV]":[
                0.01, 0.03, 0.05, 0.07, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6,
                0.65, 0.7, 0.8, 1.0, 1.4, 1.8, 2.2, 2.6, 2.8, 3.25, 3.75, 4.25, 4.75, 5.0, 5.25,
                5.75, 6.25, 6.75, 7.5, 9.0, 11.0, 13.0, 15.0
            ],
            "Conversion Factor":{
                "units":"[(rem/hr)/(cm$^{-2}\\cdot$s$^{-1}$)",
                "values":
                [
                3.96E-6, 5.82E-7, 2.9E-7, 2.58E-7, 2.83E-7, 3.79E-7, 5.01E-7, 6.31E-7, 7.59E-7,
                8.78E-7, 9.85E-7, 1.08E-6, 1.11E-6, 1.27E-6, 1.36E-6, 1.44E-6, 1.52E-6, 1.68E-6,
                1.98E-6, 2.51E-6, 2.99E-6, 3.42E-6, 3.82E-6, 4.01E-6, 4.41E-6, 4.83E-6, 5.23E-6,
                5.6E-6, 5.8E-6, 6.01E-6, 6.37E-6, 6.74E-6, 7.11E-6, 7.66E-6, 8.77E-6, 1.03E-5,
                1.18E-5, 1.33E-5
                ]
            },
            "reference":"J. Kulesza, et al.,'MCNP Code Version 6.3.0 Theory & User Manual,' Los Alamos National Laboratory, Los Alamos, NM, USA, Tech. Rep. LA-UR-22-30006, Rev. 1, Sep. 2022. ANSI/ANS-6.1.1-1977, Table 3"
            },
            "Equipment":{
    "units":"[rad (Si)]",
    "values":"3.4350364E-10  3  -5  -6",
    "reference":"MatMCNP, K. R. DePriest"
      }
        }
    },
    "Systems Data":{

        "System_1_Name":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 62395 28185",
            "Elevation (MSL) [m]": 1488,
                  "R95 [km]": 0,
                  "Depth [m]":0,
            "Heading [grid deg]": 315
            }
        },
        "System_2_Name":{
          "GIS Data":{
            "Location (MGRS)": "13SCT63922833",
            "Elevation (MSL) [m]": 1521,
                  "R95 [km]": 0,
                  "Depth [m]":0,
            "Heading [grid deg]": 90
            }

        }
    },
    "Transport Materials":{
        "Surface":{
```

```
            "Name":"Earth, U.S. Average",
            "Density [g/cm^3]":1.52,
            "Composition":{
                "8016":-0.512323,
                "8017":-0.000207,
                "11023":-0.006140,
                "12000":-0.013304,
                "13027":-0.068564,
                "14000":-0.271180,
                "19000":-0.014327,
                "20000":-0.051166,
                "22000":-0.004604,
                "25055":-0.000715,
                "26000":-0.056285
            },
            "Notes":"R. Detwiler, et al., 'Compendium of Material Composition Data for Radiation Transport Modeling,' Pacific Northwest National Laboratory, Richland, WA PNNL-15870, Rev. 2, Apr. 2021; Table 116; O-18 neglected to permit ENDF/B-VII use"
        },
        "Atmosphere":{
            "Name":"Air (dry, near sea level)",
            "Density [g/cm^3]":0.001205,
            "Composition":{
                "6000":-0.000124,
                "7014":-0.752316,
                "7015":-0.002944,
                "8016":-0.231153,
                "8017":-0.000094,
                "18000":-0.012827
            },
            "Notes":"R. Detwiler, et al., 'Compendium of Material Composition Data for Radiation Transport Modeling,' Pacific Northwest National Laboratory, Richland, WA PNNL-15870, Rev. 2, Apr. 2021; Table 4; O-18 neglected to permit ENDF/B-VII use"
        },
        "Detector":{

            "Name":"Silicon",
            "Density [g/cm^3]":2.33,
            "Composition":{
                "14028":0.92223,
                "14029":0.04685,
                "14030":0.03092
            },
            "Notes":"Nuclear Wallet Cards - Electronic Version, provided by K. R. DePriest"
        }
    },

    "Developer Name":"R. Boone Gilbreath",
    "Developer Title":"Major, U.S. Army",
    "Developer Organization":"Radiation Transport Applications Group, Los Alamos National Laboratory",

    "Maintainer":"W. C. Rinke",
    "Maintainer Title":"Analyst",
    "Maintainer Organization":"NuSCAP, LLC"
}
```

D.5 SNEC Files

Examples of SNEC input, output, and batch files are provided here for reference. The execution of SNEC commands and parsing of SNEC results is completely transparent to the NuSCAP user. These files are accessible in the SNEC subdirectory of each analytical scenario working directory after execution of a NuSCAP simulation.

D.5.1 SNEC Input File

Listing D.10: An example of a Simple Nuclear Effects Calculator input file (Example.SNEC.in)

```
Yield_(kt)    HOB_(m)    Vis_(m)
24.8          30.48006   50000
(15,1501)    (3,1501)    (12,1501)    (1183,1488)    (1196,1521)

# ------------------------------------------------------------------------------
#
# Comments that follow do not appear in a standard SNEC input file!
#
# The first line is header information specifying the value and units of entries
# in the second line.  The third line specifies range, elevation pairs
# representing all elements of the SOS.  Each may be interpreted as:
# e.g., (15 m from AGZ, 1501 m above MSL elevation).
#
# ------------------------------------------------------------------------------
```

D.5.2 SNEC Output File

Listing D.11: An example of a Simple Nuclear Effects Calculator output file (Example.SNEC.out)

```
Yield_(kt)  HOB_(m) Vis_(m)
24.8  30.48006  50000

Ground_Range_(m) 1.500E01
Elevation_(m) 1.501E03
Static_Overpressure_(psi) 3.829E05
Dynamic_Pressure_(psi) 1.503E06
Wind_Velocity_(m/sec) 4.704E04
Time_of_Arrival_(sec) 7.091E-04
In_Mach_Reflection NO
Thermal_Fluence_(cal/cm^2) ?
Initial_Dose_rad(Ti) 6.889E07
Neutron_Dose_rad(Ti) 5.920E07
Gamma_Dose_rad(Ti) 9.689E06
48hr_Fallout_Dose_rad(Ti) 2.083E03

Ground_Range_(m) 3.000E00
Elevation_(m) 1.501E03
Static_Overpressure_(psi) 7.364E05
Dynamic_Pressure_(psi) 2.829E06
Wind_Velocity_(m/sec) 6.516E04
Time_of_Arrival_(sec) 5.401E-04
In_Mach_Reflection NO
Thermal_Fluence_(cal/cm^2) ?
Initial_Dose_rad(Ti) ?
Neutron_Dose_rad(Ti) 0.000E00
Gamma_Dose_rad(Ti) 0.000E00
48hr_Fallout_Dose_rad(Ti) 2.084E03

Ground_Range_(m) 1.200E01
Elevation_(m) 1.501E03
Static_Overpressure_(psi) 4.884E05
Dynamic_Pressure_(psi) 1.938E06
Wind_Velocity_(m/sec) 5.316E04
Time_of_Arrival_(sec) 6.439E-04
In_Mach_Reflection NO
Thermal_Fluence_(cal/cm^2) ?
Initial_Dose_rad(Ti) 7.218E07
Neutron_Dose_rad(Ti) 6.218E07
Gamma_Dose_rad(Ti) 1.000E07
48hr_Fallout_Dose_rad(Ti) 2.083E03

Ground_Range_(m) 1.183E03
Elevation_(m) 1.488E03
Static_Overpressure_(psi) 5.932E00
Dynamic_Pressure_(psi) 9.573E-01
Wind_Velocity_(m/sec) 9.706E01
Time_of_Arrival_(sec) 1.865E00
In_Mach_Reflection YES
Thermal_Fluence_(cal/cm^2) 4.665E01
Initial_Dose_rad(Ti) 3.009E03
Neutron_Dose_rad(Ti) 1.512E03
Gamma_Dose_rad(Ti) 1.497E03
```

```
48hr_Fallout_Dose_rad(Ti) 1.976E03

Ground_Range_(m) 1.196E03
Elevation_(m) 1.521E03
Static_Overpressure_(psi) 5.809E00
Dynamic_Pressure_(psi) 9.226E-01
Wind_Velocity_(m/sec) 9.563E01
Time_of_Arrival_(sec) 1.897E00
In_Mach_Reflection YES
Thermal_Fluence_(cal/cm^2) 4.563E01
Initial_Dose_rad(Ti) 2.840E03
Neutron_Dose_rad(Ti) 1.419E03
Gamma_Dose_rad(Ti) 1.421E03
48hr_Fallout_Dose_rad(Ti) 1.975E03
```

D.5.3 SNEC Batch File

Listing D.12: An example of a Simple Nuclear Effects Calculator batch file (Example.SNEC.bat)

```
@echo off
set JAVARUNNER=..\jre\bin\java

%JAVARUNNER% -cp .\WebEffectsClasses.jar WebMultRange ~\Example.SNEC.in ~\Example.SNEC.out

# ------------------------------------------------------------------------------------------------
#
# Comments that follow do not appear in a standard SNEC batch file!
#
# All entries are required. Where "~\Example.SNEC.in" and "~\Example.SNEC.out" appear, the user
# must provide the system path to the SNEC input and output files.
#
# ------------------------------------------------------------------------------------------------
```

Appendix E

Unit Testing Modules and Data

The file listings provided in §E.1 include the `pytest` modules created to perform unit tests on the many methods within NuSCAP. The `*.json` files listed in §E.2 are those used to enable unit testing during the development of the NuSCAP application. The format and contents of these data files evolved during the application development process. Accordingly, the file listings provided here should be used only as a reference to the development process, not to the complete application. Caution should be exercised when considering the use of these data files for any purpose other than replicating the unit testing performed during NuSCAP development.

All file listings are attached to the electronic PDF version of this document.

E.1 Pytest Modules

Five program listings are provided in this section. Each one corresponds to a set of `pytest` unit tests designed to evaluate the performance of the five packages that compose the NuSCAP application.

E.1.1 Element Tests

Listing E.1: The NuSCAP element package pytest module (test_element.py)

```
#!/usr/bin/env python

"""Tests for ‘element‘ module."""

import logging
import pytest
import numpy as np
```

```
from NuSCAP.element import Element


@pytest.fixture
def lug_nut():
    lug_nut = Element(
        name="Lug Nut",
    )
    return lug_nut


def test_init(lug_nut):
    assert lug_nut.name == "Lug Nut"
    assert lug_nut.functionality == 1
    assert lug_nut.func_type == "functional"
    assert lug_nut.thresholds == {
        "static overpressure": np.inf,
        "dynamic pressure": np.inf,
        "windspeed": np.inf,
        "thermal fluence": np.inf,
        "total dose": np.inf,
        "neutron dose": np.inf,
        "neutron fluence": np.inf,
        "gamma ray dose": np.inf,
        "gamma ray dose rate": np.inf,
        "PD": np.inf,
    }
    assert lug_nut.rel_pos == [0, 0, 0]


def test__set_thresholds(lug_nut):
    thresholds = {
        "static overpressure": 10,
        "dynamic pressure": 20,
        "windspeed": 30,
        "thermal fluence": 40,
        "total dose": 41,
        "neutron dose": 32,
        "neutron fluence": 23,
        "gamma ray dose": 14,
        "gamma ray dose rate": 5,
        "PD": np.inf,
    }
    lug_nut._set_thresholds(thresholds)
    assert lug_nut.thresholds == {
        "static overpressure": 10,
        "dynamic pressure": 20,
        "windspeed": 30,
        "thermal fluence": 40,
        "total dose": 41,
        "neutron dose": 32,
        "neutron fluence": 23,
        "gamma ray dose": 14,
        "gamma ray dose rate": 5,
        "PD": np.inf,
    }

```

```
def test_thresholddict_typeerr_1(lug_nut):
    thresholds = np.pi
    with pytest.raises(
        TypeError, match="Dysfunction thresholds must be reported as a dictionary."
    ):
        lug_nut._set_thresholds(thresholds)


def test_thresholdvalue_typeerr_2(lug_nut):
    thresholds = {
        "total dose": ["a", 3, "two"],
    }
    with pytest.raises(
        TypeError, match="Threshold values must be numerical: float, int, or inf."
    ):
        lug_nut._set_thresholds(thresholds)


def test_thresholdvalue_typeerr_3(lug_nut):
    thresholds = {
        "total dose": "two",
    }
    with pytest.raises(
        TypeError, match="Threshold values must be numerical: float, int, or inf."
    ):
        lug_nut._set_thresholds(thresholds)


def test_thresholdsvalue_valueerr_1(lug_nut):
    thresholds = {
        "static overpressure": -10,
    }
    with pytest.raises(ValueError, match="Threshold values must be >=0"):
        lug_nut._set_thresholds(thresholds)


def test_thresholdsvalue_valueerr_2(lug_nut):
    thresholds = {
        "static overpressure": -1.25,
    }
    with pytest.raises(ValueError, match="Threshold values must be >=0"):
        lug_nut._set_thresholds(thresholds)


def test_check_dysfunctional(lug_nut):
    thresholds = {
        "static overpressure": 10,
        "dynamic pressure": 20,
        "windspeed": 30,
        "thermal fluence": 40,
        "total dose": 41,
        "neutron dose": 32,
        "neutron fluence": 23,
        "gamma ray dose": 14,
        "gamma ray dose rate": 5,
        "PD": np.inf,
```

```
    }

    lug_nut.wpn_envs = {
        "static overpressure": 11,
        "dynamic pressure": 29,
        "windspeed": 39.9999,
        "thermal fluence": 41,
        "total dose": 51,
        "neutron dose": 61,
        "neutron fluence": 71,
        "gamma ray dose": 80,
        "gamma ray dose rate": 41,
        "PD": 0,
    }
    lug_nut._set_thresholds(thresholds)
    lug_nut.check_functionality()
    assert lug_nut.thresholds == thresholds
    assert lug_nut.functionality == 0
    assert lug_nut.func_type == "dysfunctional"
    assert lug_nut.cause_of_dysfunction == [
        "static overpressure",
        "dynamic pressure",
        "windspeed",
        "thermal fluence",
        "total dose",
        "neutron dose",
        "neutron fluence",
        "gamma ray dose",
        "gamma ray dose rate",
    ]


def test_check_functional(lug_nut, caplog):
    thresholds = {
        "static overpressure": 10,
        "dynamic pressure": 20,
        "windspeed": 30,
        "thermal fluence": 40,
        "total dose": 41,
        "neutron dose": 32,
        "neutron fluence": 23,
        "gamma ray dose": 14,
        "gamma ray dose rate": 5,
        "PD": np.inf,
    }

    lug_nut.wpn_envs = {
        "static overpressure": 1,
        "dynamic pressure": 2,
        "windspeed": 9.9999,
        "thermal fluence": 4,
        "total dose": 5,
        "neutron dose": 1,
        "neutron fluence": 7,
        "gamma ray dose": 8,
        "gamma ray dose rate": 4,
        "PD": None,
```

```
    }
    lug_nut._set_thresholds(thresholds)
    lug_nut.check_functionality()
    assert lug_nut.functionality == 1
    assert lug_nut.func_type == "functional"
    assert lug_nut.cause_of_dysfunction == []
    assert caplog.record_tuples == [
        (
            "root",
            logging.WARNING,
            "The weapon environment PD is not available. The Lug Nut will not be evaluated against this environment.",
        )
    ]


def test_check_functionality_COD(lug_nut):
    thresholds = {
        "static overpressure": 10,
        "dynamic pressure": 20,
        "windspeed": 30,
        "thermal fluence": 40,
        "total dose": 41,
        "neutron dose": 32,
        "neutron fluence": 23,
        "gamma ray dose": 14,
        "gamma ray dose rate": 5,
        "PD": np.inf,
    }

    lug_nut.wpn_envs = {
        "static overpressure": 11,
        "dynamic pressure": 29,
        "windspeed": 39.9999,
        "thermal fluence": 41,
        "total dose": 51,
        "neutron dose": 61,
        "neutron fluence": 71,
        "gamma ray dose": 80,
        "gamma ray dose rate": 41,
        "PD": 0,
    }

    lug_nut._set_thresholds(thresholds)

    lug_nut.check_functionality()
    assert lug_nut.functionality == 0
    assert lug_nut.func_type == "dysfunctional"
    assert lug_nut.cause_of_dysfunction == [
        "static overpressure",
        "dynamic pressure",
        "windspeed",
        "thermal fluence",
        "total dose",
        "neutron dose",
        "neutron fluence",
        "gamma ray dose",
```

```
        "gamma ray dose rate",
    ]


def test_bad_keys_2(lug_nut):

    thresholds = {
        "static overpressure": 10,
        "dynamic pressure": 20,
        "windspeed": 30,
        "thermal fluence": 40,
        "total dose": 41,
        "neutron dose": 32,
        "neutron fluence": 23,
        "gamma ray dose": 14,
        "gamma ray dose rate": 5,
        "PD": np.inf,
        "NOT A THRESHOLD": 100,
    }

    with pytest.raises(
        KeyError,
        match="Check dictionaries, threshold keys are inconsistent with default keys: {'NOT A THRESHOLD
    '}.",
    ):
        lug_nut._set_thresholds(thresholds)


def test_rel_pos(lug_nut):
    rel_pos = [np.pi, 3, 2.750]
    lug_nut._set_relative_position(rel_pos)
    assert lug_nut.rel_pos == rel_pos

    rel_pos_1 = "a"
    with pytest.raises(
        TypeError, match="Relative position must be reported as a list."
    ):
        lug_nut._set_relative_position(rel_pos_1)

    rel_pos_2 = [1.24, 3.14]
    with pytest.raises(ValueError, match="The length of relative position must be 3."):
        lug_nut._set_relative_position(rel_pos_2)

    rel_pos_3 = ["a", 2, 2.75]
    with pytest.raises(
        ValueError,
        match="Relative position values must be integers or floating point numbers.",
    ):
        lug_nut._set_relative_position(rel_pos_3)
```

E.1.2 System Tests

Listing E.2: The NuSCAP system package pytest module (test_system.py)

```
#!/usr/bin/env python

```

```python
"""Tests for ‘system‘ module."""

import json
import os
import glob
from datetime import datetime
import pytest
import numpy as np
from NuSCAP.system import System

now = datetime.now()
now_str = now.strftime("%Y%m%d_%H%M%S")


@pytest.fixture
def small_sys():
    sm_sys = System(
        name="ECS",
        sdf="./tests/system/data/small_sys.json",
        scenario_data="C:/Users/339528/Documents/Git/NuSCAP/tests/system/data/SS_Scenario_Data.json",
    )
    return sm_sys


@pytest.fixture
def lg_sys():
    lg_sys = System(
        name="Degraded System",
        sdf="./tests/system/data/EPP_1_1.json",
        scenario_data="C:/Users/339528/Documents/Git/NuSCAP/tests/system/data/Scenario_Data.scdf.json",
    )
    return lg_sys


@pytest.fixture
def degraded_sys_2():
    deg_sys = System(
        name="Degraded System",
        sdf="./tests/system/data/EPP_1_2.json",
        scenario_data="C:/Users/339528/Documents/Git/NuSCAP/tests/system/data/Scenario_Data.json",
    )
    return deg_sys


@pytest.fixture
def dysf_sys():
    dysf = System(
        name="Dysfunctional System",
        sdf="./tests/system/data/dysf_sys.json",
        scenario_data="C:/Users/339528/Documents/Git/NuSCAP/tests/system/data/Dysf_Scen.json",
    )
    return dysf


@pytest.fixture
def EPP():
    EPP = System(
```

```
        name="EPP",
        sdf="./tests/system/data/small_sys.json",
        scenario_data="C:/Users/339528/Documents/Git/NuSCAP/tests/system/data/SS_Scenario_Data.json",
    )
    return EPP


@pytest.fixture
def EPP_1():
    EPP = System(
        name="Degraded System",
        sdf="./tests/system/data/EPP_1.json",
        scenario_data="C:/Users/339528/Documents/Git/NuSCAP/tests/system/data/Scenario_Data.scdf.json",
    )
    return EPP


def test_init(small_sys):
    files = glob.glob("C:/temp/Example_Scenario/ECS/*")
    for f in files:
        os.remove(f)
    os.rmdir("C:/temp/Example_Scenario/ECS")
    assert small_sys.name == "ECS"
    assert small_sys.sdf == "./tests/system/data/small_sys.json"


def test_jsonld(small_sys):
    with open(
        "C:/Users/339528/Documents/Git/NuSCAP/tests/system/data/small_sys.json", "r"
    ) as infile:
        assert small_sys.system_data == json.load(infile)


def test_mkelement(small_sys):
    assert small_sys.elements["Small System"].name == "Small System"
    assert small_sys.elements["Small System"].functionality == 1
    assert small_sys.elements["Small System"].func_type == "functional"
    assert small_sys.elements["Small System"].vntk == "null"
    assert small_sys.elements["Small System"].el_type == "equipment"
    assert small_sys.elements["Small System"].thresholds == {
        "static overpressure": np.inf,
        "dynamic pressure": np.inf,
        "windspeed": np.inf,
        "thermal fluence": np.inf,
        "total dose": np.inf,
        "neutron dose": 22,
        "neutron fluence": 2002,
        "gamma ray dose": np.inf,
        "gamma ray dose rate": np.inf,
        "PD": 0.999999,
    }
    assert small_sys.elements["Small System"].wpn_envs == {
        "static overpressure": 0,
        "dynamic pressure": 0,
        "windspeed": 0,
        "thermal fluence": 0,
        "total dose": 0,
```

```
        "neutron dose": 0,
        "neutron fluence": 0,
        "gamma ray dose": 0,
        "gamma ray dose rate": 0,
        "PD": 0,
    }

    assert small_sys.elements["Generator Set 1"].name == "Generator Set 1"
    assert small_sys.elements["Generator Set 1"].vntk == "None"
    assert small_sys.elements["Generator Set 1"].el_type== "equipment"
    assert small_sys.elements["Generator Set 1"].thresholds == {
        "static overpressure": np.inf,
        "dynamic pressure": 1,
        "windspeed": np.inf,
        "thermal fluence": 3.1415926,
        "total dose": np.inf,
        "neutron dose": 1e6,
        "neutron fluence": np.inf,
        "gamma ray dose": 1,
        "gamma ray dose rate": np.inf,
        "PD": 1,
    }
    assert small_sys.elements["Air Filter 1"].rel_pos == [0.75, 1.0, 1.25]

    assert small_sys.elements["Generator Set 2"].name == "Generator Set 2"
    assert small_sys.elements["Air Filter 2"].name == "Air Filter 2"
    assert small_sys.elements["Air Filter 2"].el_type == "equipment"
    assert small_sys.elements["Generator Set 2"].rel_pos == [2.0, 3.5, 1.25]
    assert small_sys.elements["Paper"].thresholds == {
        "static overpressure": 1.02,
        "dynamic pressure": np.inf,
        "windspeed": np.inf,
        "thermal fluence": np.inf,
        "total dose": np.inf,
        "neutron dose": np.inf,
        "neutron fluence": np.inf,
        "gamma ray dose": np.inf,
        "gamma ray dose rate": np.inf,
        "PD": np.inf,
    }
    assert small_sys.elements["Oxygen"].name == "Oxygen"
    assert small_sys.elements["Oxygen"].thresholds == {
        "static overpressure": np.inf,
        "dynamic pressure": np.inf,
        "windspeed": np.inf,
        "thermal fluence": np.inf,
        "total dose": np.inf,
        "neutron dose": np.inf,
        "neutron fluence": np.inf,
        "gamma ray dose": np.inf,
        "gamma ray dose rate": np.inf,
        "PD": 0.1725,
    }

    assert small_sys.elements["Fuel System 2"].name == "Fuel System 2"


```

```
def test_addAdminNodes(small_sys):
    keynames = set(
        [
            "Small System",
            "Generator Set 1",
            "Generator Set 2",
            "Air Filter 1",
            "Fuel System 1",
            "Filter Element",
            "Fuel Tank",
            "Diesel",
            "Carbon",
            "Air Filter 2",
            "Fuel System 2",
            "Filter Element 2",
            "Paper",
            "Oxygen",
            "AA",
            "BB",
            "CC",
            "DD",
            "EE",
            "FF",
            "Small System_X",
            "Small System_XX",
        ]
    )
    assert keynames == small_sys.elements.keys()


def test_checkNodes(small_sys):
    list = []
    for n in small_sys.sys_graph.nodes:
        list.append(n)
    assert list == [
        "Small System",
        "Generator Set 1",
        "Generator Set 2",
        "Air Filter 1",
        "Fuel System 1",
        "Filter Element",
        "Fuel Tank",
        "Diesel",
        "Carbon",
        "Air Filter 2",
        "Fuel System 2",
        "Filter Element 2",
        "Paper",
        "Oxygen",
        "AA",
        "BB",
        "CC",
        "DD",
        "EE",
        "FF",
        "Small System_X",
        "Small System_XX",
```

```
    ]
    assert small_sys.sys_graph.nodes["Small System"]["element"].vntk == "null"
    assert small_sys.sys_graph.nodes["Fuel System 2"]["element"].name == "Fuel System 2"
    assert (
        small_sys.sys_graph.nodes["Filter Element"]["element"].thresholds["windspeed"]
        == 50
    )


def test_edges(small_sys):
    list = []
    for e in small_sys.sys_graph.edges:
        list.append(e)
    edges = [
        ("Small System_X", "Small System"),
        ("Small System", "AA"),
        ("AA", "Generator Set 1"),
        ("AA", "Generator Set 2"),
        ("Generator Set 1", "Air Filter 1"),
        ("Generator Set 1", "Fuel System 1"),
        ("Air Filter 1", "Filter Element"),
        ("Filter Element", "BB"),
        ("Fuel System 1", "Fuel Tank"),
        ("Fuel Tank", "Diesel"),
        ("Diesel", "Carbon"),
        ("Carbon", "CC"),
        ("Generator Set 2", "Fuel System 2"),
        ("Generator Set 2", "Air Filter 2"),
        ("Fuel System 2", "EE"),
        ("Air Filter 2", "Filter Element 2"),
        ("Filter Element 2", "Paper"),
        ("Paper", "Oxygen"),
        ("Oxygen", "DD"),
        ("BB", "FF"),
        ("CC", "FF"),
        ("DD", "FF"),
        ("EE", "FF"),
        ("FF", "Small System_XX"),
    ]
    diff = set(edges) - set(list)
    assert diff == set()


def test_disconnect(small_sys):
    small_sys.sys_graph.remove_edge("Small System_X", "Small System")
    with pytest.raises(
        ValueError, match="Node Small System_X is not connected to any other node!"
    ):
        small_sys._check_degrees()


def test_save_graph(small_sys):
    small_sys.calculate_ranges()
    assert small_sys.range_to_gz == 18
    small_sys.save_graph()

```

```
def test_bad_mgrs(EPP):
    with pytest.raises(
        ValueError,
        match=str(
            "An invalid MGRS grid is associated with EPP!"
            + "\n"
            + "Check grid data and try again."
        ),
    ):
        EPP.calculate_ranges()


def test_ranges(lg_sys, degraded_sys_2, dysf_sys):
    lg_sys.calculate_ranges()
    lg_sys.save_graph()
    assert lg_sys.range_to_gz == 10

    degraded_sys_2.calculate_ranges()
    assert degraded_sys_2.range_to_gz == 100

    dysf_sys.calculate_ranges()
    assert dysf_sys.range_to_gz == 10293000


def test_evaluate(dysf_sys):
    dysf_sys.sys_graph.nodes["Generator Set 1"]["element"].wpn_envs = {
        "static overpressure": 0.036502182483673096,
        "dynamic pressure": 2,
        "windspeed": 0,
        "thermal fluence": 0,
        "total dose": 0,
        "neutron dose": 2,
        "neutron fluence": 0,
        "gamma ray dose": 2,
        "gamma ray dose rate": 0,
        "PD": 0,
    }

    dysf_sys.sys_graph.nodes["Generator Set 2"]["element"].wpn_envs = {
        "static overpressure": 0.036502182483673096,
        "dynamic pressure": 2,
        "windspeed": 0,
        "thermal fluence": 0,
        "total dose": 0,
        "neutron dose": 2,
        "neutron fluence": 0,
        "gamma ray dose": 2,
        "gamma ray dose rate": 0,
        "PD": 0,
    }

    dysf_sys.sys_graph.nodes["Diesel"]["element"].wpn_envs = {
        "static overpressure": 0.036502182483673096,
        "dynamic pressure": 2,
        "windspeed": 0,
        "thermal fluence": 0,
        "total dose": 0,
```

```
        "neutron dose": 2,
        "neutron fluence": 11.999,
        "gamma ray dose": 2,
        "gamma ray dose rate": 0,
        "PD": 0,
    }

    dysf_sys.sys_graph.nodes["Paper"]["element"].wpn_envs = {
        "static overpressure": 0.036502182483673096,
        "dynamic pressure": 2,
        "windspeed": 0,
        "thermal fluence": 0,
        "total dose": 0,
        "neutron dose": 2,
        "neutron fluence": 0,
        "gamma ray dose": 2,
        "gamma ray dose rate": 0,
        "PD": 0,
    }

    dysf_sys.calculate_ranges()
    dysf_sys.evaluate_nodes()
    dysf_sys.evaluate_system_functionality()
    dysf_sys.evaluate_capabilities()
    dysf_sys.save_graph()
    dysf_sys.report()

    assert dysf_sys.sys_graph.nodes["Air Filter 1"]["element"].functionality == 1
    assert dysf_sys.sys_graph.nodes["Air Filter 2"]["element"].functionality == 1
    assert dysf_sys.sys_graph.nodes["Fuel System 1"]["element"].functionality == 1
    assert dysf_sys.sys_graph.nodes["Fuel System 2"]["element"].functionality == 1
    assert dysf_sys.sys_graph.nodes["Carbon"]["element"].functionality == 1
    assert dysf_sys.sys_graph.nodes["Diesel"]["element"].functionality == 1
    assert dysf_sys.sys_graph.nodes["Filter Element"]["element"].functionality == 1
    assert dysf_sys.sys_graph.nodes["Filter Element 2"]["element"].functionality == 1
    assert dysf_sys.sys_graph.nodes["Fuel Tank"]["element"].functionality == 1
    assert dysf_sys.sys_graph.nodes["Oxygen"]["element"].functionality == 1
    assert dysf_sys.sys_graph.nodes["Paper"]["element"].functionality == 1
    assert (
        dysf_sys.sys_graph.nodes["Dysfunctional System"]["element"].functionality == 1
    )

    assert dysf_sys.sys_graph.nodes["Generator Set 1"]["element"].functionality == 0
    assert dysf_sys.sys_graph.nodes["Generator Set 2"]["element"].functionality == 0
    assert dysf_sys.functionality == 0
    assert dysf_sys.func_type == "dysfunctional"

    assert dysf_sys.sys_graph.nodes["Generator Set 1"][
        "element"
    ].cause_of_dysfunction == ["dynamic pressure", "gamma ray dose"]
    assert dysf_sys.sys_graph.nodes["Generator Set 2"][
        "element"
    ].cause_of_dysfunction == ["static overpressure"]

    assert (
        dysf_sys.residual_capabilities["Powers External Loads"]["Maximum Capability"]
        == "Cannot provide power to ECS or RS"
```

```
    )
    assert (
        dysf_sys.residual_capabilities["R/T Short-Range Communications"][
            "Maximum Capability"
        ]
        == "Cannot R/T short-range data communications"
    )


def test_bad_cap_bins(EPP_1):
    EPP_1._build_graph()
    EPP_1.calculate_ranges()
    EPP_1.evaluate_nodes()
    EPP_1.evaluate_system_functionality()

    with pytest.raises(
        ValueError,
        match="Check bin structure for R/T Short-Range Communications. Second bin must start with 'NOT POSSIBLE'.",
    ):
        EPP_1.evaluate_capabilities()
```

E.1.3 SOS Tests

Listing E.3: The NuSCAP sos package pytest module (test_sos.py)

```python
#!/usr/bin/env python

"""Tests for 'SOS' (system-of-systems) module."""

import json
import os
from datetime import datetime
import pytest
import numpy as np
from NuSCAP.sos import SOS
import matplotlib.pyplot as plt


@pytest.fixture
def demo_SOS():
    sos = SOS(
        name="Demo",
        sosdf="./tests/sos/Demo_SOS/Demo.sosdf.json",
        scenario_data="./tests/sos/Demo_SOS/Demo.scdf.json",
    )
    return sos


@pytest.fixture
def degraded_SOS():
    deg_sos = SOS(
        name="Degraded SOS",
        sosdf="./tests/sos/Demo_SOS/Degraded.sosdf.json",
        scenario_data="./tests/sos/Demo_SOS/Degraded.scdf.json",
    )
    return deg_sos


@pytest.fixture
def erroneous_SOS():
    erroneous = SOS(
        name="Degraded SOS",
        sosdf="./tests/sos/Demo_SOS/Errors.sosdf.json",
        scenario_data="./tests/sos/Demo_SOS/Errors.scdf.json",
    )
    return erroneous


@pytest.fixture
def erroneous_SOS2():
    erroneous2 = SOS(
        name="Degraded SOS",
        sosdf="./tests/sos/Demo_SOS/Errors.sosdf.json",
        scenario_data="./tests/sos/Demo_SOS/Errors_2.scdf.json",
    )
    return erroneous2


```

```python
def test_init(demo_SOS):
    assert demo_SOS.name == "Demo"
    assert demo_SOS.sosdf == "./tests/sos/Demo_SOS/Demo.sosdf.json"
    with open("./tests/sos/Demo_SOS/Demo.scdf.json", "r") as file:
        assert demo_SOS.scenario_data == json.load(file)


def test_show_graph(degraded_SOS):
    degraded_SOS.construct_sos_graph()
    degraded_SOS.show_sos_graph()

def test_calc_rng(demo_SOS):
    demo_SOS.construct_sos_graph()
    demo_SOS.save_sos_graph()
    demo_SOS.evaluate_sos()
    assert demo_SOS.systems["System 1"].range_to_gz == 15
    assert demo_SOS.systems["System 2"].range_to_gz == 3
    assert demo_SOS.systems["System 3"].range_to_gz == 10
    assert demo_SOS.systems["System 5.1"].range_to_gz == 1200
    assert demo_SOS.systems["System 5.2"].range_to_gz == 1196


def test_bad_MGRS(erroneous_SOS):
    erroneous_SOS.construct_sos_graph()
    with pytest.raises(
        ValueError,
        match=(
            "An invalid MGRS grid is associated with System 3!"
            + "\n"
            + "Check grid data and try again."
        ),
    ):
        erroneous_SOS.evaluate_sos()


def test_dysfunctional_system(erroneous_SOS2):
    erroneous_SOS2.construct_sos_graph()
    erroneous_SOS2.evaluate_sos()
    erroneous_SOS2.check_sos_functionality()

    assert erroneous_SOS2.systems["System 3"].functionality == 0
    assert erroneous_SOS2.functionality == 0

    with pytest.raises(
        ValueError,
        match="Check bin structure for Power Core Systems. Second bin must start with 'NOT POSSIBLE'.",
    ):
        erroneous_SOS2.evaluate_sos_capabilities()


def test_capability_bins(degraded_SOS):
    degraded_SOS.construct_sos_graph()
    degraded_SOS.evaluate_sos()
    degraded_SOS.check_sos_functionality()
    degraded_SOS.evaluate_sos_capabilities()

    # Test capability bin 3 (first degraded state)
```

```
    assert degraded_SOS.systems["System 3"].elements["J3_3"].functionality == 0
    assert (
        degraded_SOS.residual_capabilities["Power Core Systems"]["Maximum Capability"]
        == "Power System 1 and 3 ONLY"
    )

    # Test capability bin 1 (fully capable state)
    assert (
        degraded_SOS.residual_capabilities["Control/Monitor Power Generation"][
            "Maximum Capability"
        ]
        == "Control Power Generation via cable and control panel"
    )

    # Test capability bin 4 (second degraded state)
    assert degraded_SOS.systems["System 1"].elements["VHF Antenna 1"].functionality == 0
    assert (
        degraded_SOS.residual_capabilities["Control/Monitor Weapon System 5.1"][
            "Maximum Capability"
        ]
        == "Control/monitor System 5.1 via OF ONLY"
    )

    # Test capability bin 2 (incapable state)
    assert degraded_SOS.systems["System 1"].elements["VHF Antenna 1"].functionality == 0
    assert (
        degraded_SOS.systems["System 1"].elements["Fiber Optic Cable 1.2"].functionality
        == 0
    )
    assert (
        degraded_SOS.residual_capabilities["Control/Monitor Weapon System 5.2"][
            "Maximum Capability"
        ]
        == "Cannot control/monitor System 5.2"
    )

    assert degraded_SOS.functionality == 1


def test_outputs(degraded_SOS):
    degraded_SOS.construct_sos_graph()
    degraded_SOS.evaluate_sos()
    degraded_SOS.check_sos_functionality()
    degraded_SOS.evaluate_sos_capabilities()
    degraded_SOS.save_sos_graph()
    degraded_SOS.sos_report()
```

E.1.4 Weapon Environment Tools (EnvTools) Tests

Listing E.4: The NuSCAP weapon environment tools package pytest module (test_env_tools.py)

```
#!/usr/bin/env python

"""Tests for env_tools (weapon environment tools) module."""

import logging
import glob
import os
import pytest
import json
import numpy as np
from NuSCAP.sos import SOS
from NuSCAP.env_tools import EnvTools


@pytest.fixture
def demo_SOS():
    sos = SOS(
        name="Demo",
        sosdf="./tests/sos/Demo_SOS/Demo.sosdf.json",
        scenario_data="./tests/sos/Demo_SOS/Demo.scdf.json",
    )
    return sos

@pytest.fixture
def mcnp_tiny_SOS():
    tiny_SOS = SOS(
        name="Tiny",
        sosdf="./tests/sos/Demo_SOS/Tiny.sosdf.json",
        scenario_data="./tests/sos/Demo_SOS/MCNP_demo.scdf.json"
    )
    return tiny_SOS

@pytest.fixture
def calc_1(demo_SOS):
    wpn_calc_1 = EnvTools(sos=demo_SOS, scenario=demo_SOS.scenario_data)
    return wpn_calc_1


def test_init(calc_1):
    with open("./tests/sos/Demo_SOS/Demo.scdf.json", "r") as file:
        expected = json.load(file)

    assert calc_1.sos.name == "Demo"
    assert calc_1.scen_data == expected


def test_pdcalc(demo_SOS):
    demo_SOS.construct_sos_graph()
    demo_SOS.evaluate_sos()

    assert np.isclose(
        [
            demo_SOS.sos_graph.nodes["System 1"]["element"].wpn_envs[
```

```
                "static overpressure"
            ]
        ],
        [411720],
    )
    assert np.isclose(
        [demo_SOS.sos_graph.nodes["System 1"]["element"].wpn_envs["dynamic pressure"]],
        [13616],
    )

    assert np.isclose(
        [demo_SOS.sos_graph.nodes["System 5.1"]["element"].wpn_envs["PD"]], [0.43]
    )
    assert np.isclose(
        [
            demo_SOS.sos_graph.nodes["System 5.1"]["element"].wpn_envs[
                "static overpressure"
            ]
        ],
        [6.2417],
    )
    assert np.isclose(
        [
            demo_SOS.sos_graph.nodes["System 5.1"]["element"].wpn_envs[
                "dynamic pressure"
            ]
        ],
        [0.88462],
    )


def test_snec(demo_SOS):
    infiles = glob.glob("C:/temp/Demo_SOS/Demo_Scenario/SNEC/Input/*")
    for f in infiles:
        os.remove(f)

    os.rmdir("C:/temp/Demo_SOS/Demo_Scenario/SNEC/Input")

    outfiles = glob.glob("C:/temp/Demo_SOS/Demo_Scenario/SNEC/Output/*")
    for f in outfiles:
        os.remove(f)

    os.rmdir("C:/temp/Demo_SOS/Demo_Scenario/SNEC/Output")

    demo_SOS.construct_sos_graph()
    demo_SOS.evaluate_sos()

    assert demo_SOS.sos_graph.nodes["System 1"]["element"].wpn_envs["thermal fluence"] is None
    assert np.isclose([demo_SOS.sos_graph.nodes["System 5.1"]["element"].wpn_envs["windspeed"]],[94.99])
    assert np.isclose([demo_SOS.sos_graph.nodes["System 5.1"]["element"].wpn_envs["thermal fluence"
    ]],[45.32])

def test_mcnp_in(mcnp_tiny_SOS):

    infiles = glob.glob("C:/temp/Demo_SOS/Demo_Scenario/MCNP/Input/*")
    for f in infiles:
        os.remove(f)
```

```
110
111     os.rmdir("C:/temp/Demo_SOS/Demo_Scenario/MCNP/Input")
112
113     outfiles = glob.glob("C:/temp/Demo_SOS/Demo_Scenario/MCNP/Output/*")
114     for f in outfiles:
115         os.remove(f)
116
117     os.rmdir("C:/temp/Demo_SOS/Demo_Scenario/MCNP/Output")
118
119     mcnp_tiny_SOS.construct_sos_graph()
120     mcnp_tiny_SOS.evaluate_sos()
121
122 # [ ] TODO: Add unit tests for dose, dose rate, and fluence calcs
```

E.2 Supporting Data Files

The data files contained in this section are composed for the express purpose of supporting `pytest` unit testing of the NuSCAP application's Python packages. While these data files closely resemble those used in the case study, subtle differences in formatting or content may exist. Caution should be exercised when considering the use of these data files for any purpose other than replicating the unit testing performed during NuSCAP development.

E.2.1 Element Test Data

No data files were required to support unit testing of the Element package.

E.2.2 System Test Data

E.2.2.1 System Data Files

Listing E.5: The dysf_sys system data file (dysf_sys.json)

```
{
  "HEADER COMMENTS":"The following data defines an example 'small system' used to develop the System
     class module for NuSCAP",
  "System":{
    "Dysfunctional System":{
      "ID": "EPP_Main",
      "type":"equipment",
                "color": "#EB0F1E",
      "VNTK": "null",

      "thresholds":{
        "static overpressure": 100,
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": 22,
        "neutron fluence": 2002,
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": 0.82387
      }
    }
  },

  "Subsystems":{

    "Generator Set 1":{

      "ID":"GS1_Main",
                "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": 1,
        "windspeed": "inf",
        "thermal fluence": 3.1415926,
        "total dose": "inf",
        "neutron dose": 1E6,
        "neutron fluence": "inf",
        "gamma ray dose": 1,
        "gamma ray dose rate": "inf",
        "PD": 1
      },
      "Components":{
        "Air Filter 1":{
          "ID":"AIR_1",
                           "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
```

```
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": 1},

          "Components":{
            "Filter Element":{
              "ID":"Filter_1",
                                    "type":"equipment",
              "relative position":[0,0,0],
              "thresholds":{
                "windspeed":50
              }
            }
          }
        },
        "Fuel System 1":{
          "ID":"FUEL_1",
                          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": 1},
          "Components":{
            "Fuel Tank":
            {
              "ID": "Fuel Tank",
                                    "type":"equipment",
              "relative position":[0,0,0],
              "thresholds":{
                "total dose": 124
                },
              "Components":{
                "Diesel":{
                  "ID": "Diesel",
                                              "type":"equipment",
                  "relative position":[0,0,0],
                  "thresholds":{
                    "thermal fluence": 12
                    },
                  "Components":{
                    "Carbon":{
                      "ID": "C",
                      "type":"equipment",
```

```
                    "relative position":[0,0,0],
                    "thresholds":{
                      "PD":0.963
                    }
                  }
                }
                }
           }}
         }
       }

     }
       },

   "Generator Set 2":{

     "ID":"GS2_Main",
               "type":"equipment",
     "relative position":[0,0,0],

     "thresholds":{
       "static overpressure": 0.01,
       "dynamic pressure": "inf",
       "windspeed": "inf",
       "thermal fluence": "inf",
       "total dose": "inf",
       "neutron dose": "inf",
       "neutron fluence": "inf",
       "gamma ray dose": "inf",
       "gamma ray dose rate": "inf",
       "PD": 0.995
     },
     "Components":{
       "Air Filter 2":{
         "ID":"AIR_2",
                         "type":"equipment",
         "relative position":[0,0,0],
         "thresholds":{
           "static overpressure": "inf",
           "dynamic pressure": "inf",
           "windspeed": "inf",
           "thermal fluence": "inf",
           "total dose": "inf",
           "neutron dose": "inf",
           "neutron fluence": "inf",
           "gamma ray dose": "inf",
           "gamma ray dose rate": "inf",
           "PD": 1},
           "Components":{
             "Filter Element 2":
             {
               "ID": "Filter_2",
                                      "type":"equipment",
               "relative position":[0,0,0],
               "thresholds":{
                 "thermal fluence": 6.25
                 },
```

```
                "Components":{
                  "Paper":{
                    "ID": "Paper",
                                                  "type":"equipment",
                    "relative position":[0,0,0],
                    "thresholds":{
                      "static overpressure": 1.02
                      },
                    "Components":{
                      "Oxygen":{
                        "ID": "O",
                                                          "type":"equipment",
                        "relative position":[0,0,0],
                        "thresholds":{
                          "PD":0.1725
                        }
                    }
                  }
                }
              }
                    }
        }
      },
        "Fuel System 2":{
          "ID":"FUEL_2",
                          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": 1}
        }
        }
            }
        },

    "functions":"This is a placeholder for future work using subsystem and system functions underlying
     system capabilities.",

  "capabilities":{
    "Powers External Loads":[
      {"Power All Loads":{
        "Begin Node":["Dysfunctional System_X"],
        "End Node":["FF"],
        "Has Path":[true],
        "Comment":"Provides power to both ECS and RS"
      }},
            {"NOT POSSIBLE":{
        "Begin Node":["Dysfunctional System_X"],
        "End Node":["FF"],
```

```
        "Has Path":[false],
        "Comment":"Cannot provide power to ECS or RS"
      }},
      {"Power Load A":{
        "Begin Node":["Dysfunctional System_X"],
        "End Node":["AA"],
        "Has Path":[false],
        "Comment":"Provides power ECS only"
      }},
      {"Power Load B":{
        "Begin Node":["Dysfunctional System_X"],
        "End Node":["Dysfunctional System"],
        "Has Path":[false],
        "Comment":"Provides power RS only"
      }}
    ],
    "R/T Short-Range Communications":[
        {"Coms Possible":{
          "Begin Node":["Dysfunctional System_X"],
          "End Node":["BB"],
          "Has Path":[true],
          "Comment":"R/T data with ECS via J5 cable"
        }},
                {"NOT POSSIBLE":{
          "Begin Node":["Dysfunctional System_X"],
          "End Node":["Dysfunctional System_XX"],
          "Has Path":[false],
          "Comment":"Cannot R/T short-range data communications"
        }},
        {"Degraded Coms":{
          "Begin Node":["Dysfunctional System_X"],
          "End Node":["DD"],
          "Has Path":[true],
          "Comment":"R/T data only via PDU control panel manual operation"
        }}
      ]
        },
  "Structure":{
    "Admin Nodes":["AA", "BB", "CC", "DD", "EE", "FF"],
        "Terminal Nodes":["Dysfunctional System_X", "Dysfunctional System_XX"],
    "Edges":{
      "Dysfunctional System_X":["Dysfunctional System"],
      "Dysfunctional System":["AA"],
      "AA":["Generator Set 1",  "Generator Set 2"],
      "Generator Set 1":["Air Filter 1", "Fuel System 1"],
      "Air Filter 1":["Filter Element"],
      "Filter Element":["BB"],
      "Fuel System 1":["Fuel Tank"],
      "Fuel Tank":["Diesel"],
      "Diesel":["Carbon"],
      "Carbon":["CC"],
      "Generator Set 2":["Fuel System 2", "Air Filter 2"],
      "Fuel System 2":["EE"],
      "Air Filter 2":["Filter Element 2"],
      "Filter Element 2":["Paper"],
      "Paper":["Oxygen"],
      "Oxygen":["DD"],
```

```
      "BB":["FF"],
      "CC":["FF"],
      "DD":["FF"],
      "EE":["FF"],
      "FF":["Dysfunctional System_XX"]
    }
  }
    }
```

Listing E.6: The EPP_1 system data file (EPP_1.json)

```
{
  "HEADER COMMENTS":"The following data defines the Electric Power Plant system.",
  "System":{
        "EPP":{
            "ID": "EPP",
      "type":"equipment",
            "color": "#EB0F1E",
            "VNTK": "20P4",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Generator Set 1":{

      "ID":"GS_1",
                "VNTK":"null",
      "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": 1,
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "Air Filter 1":{
          "ID":"AIR_1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
```

```
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Fuel System 1":{
          "ID":"FUEL_1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Engine 1":{
          "ID":"ENG_1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N1 1":{
          "ID":"N1_1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
```

```
        },
        "N4 1":{
          "ID":"N4_1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Generator 1":{
          "ID":"GEN_1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N2 1":{
          "ID":"N2_1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N3 1":{
          "ID":"N3_1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
```

```
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K1 1":{
          "ID":"K1_1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }}},

    "Generator Set 2":{

      "ID":"GS_2",
      "VNTK": "null",
      "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "Air Filter 2":{
          "ID":"AIR_2",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
```

```
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Fuel System 2":{
          "ID":"FUEL_2",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Engine 2":{
          "ID":"ENG_2",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N1 2":{
          "ID":"N1_2",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
```

```
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N4 2":{
          "ID":"N4_2",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Generator 2":{
          "ID":"GEN_2",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N2 2":{
          "ID":"N2_2",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N3 2":{
          "ID":"N3_2",
```

```
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K1 2":{
          "ID":"K1_2",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }}},

    "Power Distribution Unit":{

      "ID":"PDU_MAIN",
      "VNTK": "null",
      "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "PDU_CTRL":{
          "ID":"PDU_CTRL",
          "VNTK": "null",
          "type":"equipment",
```

```
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "PDU Synchronizer":{
          "ID":"PDU_SYNCH",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "L1 Bus Bar":{
          "ID":"L1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "L2 Bus Bar":{
          "ID":"L2",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
```

```
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "L3 Bus Bar":{
          "ID":"L3",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Neutral Bus Bar":{
          "ID":"NEUTRAL",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T1":{
          "ID":"T1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
```

```
        },
        "T2":{
          "ID":"T2",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T3":{
          "ID":"T3",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T4":{
          "ID":"T4",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T5":{
          "ID":"T5",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
```

```
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T6":{
          "ID":"T6",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T7":{
          "ID":"T7",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T8":{
          "ID":"T8",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
```

```
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T9":{
          "ID":"T9",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T10":{
          "ID":"T10",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T11":{
          "ID":"T11",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
```

```
        "T12":{
          "ID":"T12",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K3":{
          "ID":"K3",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K4":{
          "ID":"K4",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K5":{
          "ID":"K5",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
```

```
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K6":{
          "ID":"K6",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J1":{
          "ID":"K7",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J2":{
          "ID":"J2",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
```

```
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J3":{
          "ID":"J3",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J4":{
          "ID":"J4",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 3,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J5":{
          "ID":"J5",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
        }}},
```

```
855
856   "functions":"This is a placeholder for future work using subsystem and system functions underlying
        system capabilities.",
857
858   "capabilities":{
859     "Powers External Loads":[
860             {"Powers ECS & RS":{
861         "Begin Node":["EPP_X", "EPP_X"],
862         "End Node":["CC", "DD"],
863         "Has Path":[true, true],
864         "Comment":"Provides power to both ECS and RS"
865       }},
866       {"NOT POSSIBLE":{
867         "Begin Node":["EPP_X"],
868         "End Node":["FF"],
869         "Has Path":[false],
870         "Comment":"Cannot provide power to ECS or RS"
871       }},
872       {"Powers ECS Only":{
873         "Begin Node":["EPP_X"],
874         "End Node":["DD"],
875         "Has Path":[true],
876         "Comment":"Provides power to ECS only"
877       }},
878       {"Powers RS Only":{
879         "Begin Node":["EPP_X"],
880         "End Node":["CC"],
881         "Has Path":[true],
882         "Comment":"Provides power to RS only"
883       }}
884         ],
885     "R/T Short-Range Communications":[
886             {"NOT POSSIBLE":{
887         "Begin Node":["EPP_X"],
888         "End Node":["PDU_CTRL"],
889         "Has Path":[false],
890         "Comment":"Cannot R/T short-range data communications"
891       }},
892             {"R/T Data via J5 Cable or PDU Panel":{
893                 "Begin Node":["EPP_X"],
894         "End Node":["EE"],
895         "Has Path":[true],
896         "Comment":"R/T short-range data via J5 cable or PUD control panel manual operation"
897             }},
898       {"R/T Data via PDU Panel":{
899         "Begin Node":["EPP_X"],
900         "End Node":["PDU_CTRL"],
901         "Has Path":[true],
902         "Comment":"R/T data only via PDU control panel manual operation"
903       }}
904         ]
905   },
906
907   "Structure":{
908     "Admin Nodes":["AA","BB","CC","DD","EE","FF"],
909         "Terminal Nodes":["EPP_X", "EPP_XX"],
910     "Edges":{
```

```
      "EPP_X":["EPP"],
      "EPP":["AA"],
      "AA":["Generator Set 1", "Generator Set 2"],
      "Generator Set 1":["Air Filter 1"],
      "Air Filter 1":["Fuel System 1"],
      "Fuel System 1":["Engine 1"],
      "Engine 1":["N1 1"],
      "N1 1":["N4 1"],
      "N4 1":["Generator 1"],
      "Generator 1":["N2 1"],
      "N2 1":["N3 1"],
      "N3 1":["K1 1"],
      "K1 1":["BB"],
      "Generator Set 2":["Air Filter 2"],
      "Air Filter 2":["Fuel System 2"],
      "Fuel System 2":["Engine 2"],
      "Engine 2":["N1 2"],
      "N1 2":["N4 2"],
      "N4 2":["Generator 2"],
      "Generator 2":["N2 2"],
      "N2 2":["N3 2"],
      "N3 2":["K1 2"],
      "K1 2":["BB"],
      "BB":["Power Distribution Unit"],
      "Power Distribution Unit":["PDU_CTRL"],
      "PDU_CTRL":["PDU Synchronizer", "J5"],
      "J5":["EE"],
      "EE":["EPP_XX"],
      "PDU Synchronizer":["L1 Bus Bar"],
      "L1 Bus Bar":["L2 Bus Bar"],
      "L2 Bus Bar":["L3 Bus Bar"],
      "L3 Bus Bar":["Neutral Bus Bar"],
      "Neutral Bus Bar":["T1", "T10"],
      "T1":["T2"],
      "T2":["T3"],
      "T3":["T4"],
      "T4":["T5"],
      "T5":["T6"],
      "T6":["T7"],
      "T7":["T8"],
      "T8":["T9"],
      "T9":["K3"],
      "K3":["K4"],
      "K4":["K5"],
      "K5":["J1"],
      "J1":["J2"],
      "J2":["J3"],
      "J3":["CC"],
      "T10":["T11"],
      "T11":["T12"],
      "T12":["K6"],
      "K6":["J4"],
      "J4":["DD"],
            "CC":["FF"],
      "DD":["FF"],
      "FF":["EPP_XX"]
   }
```

```
968     }
969 }
```

Listing E.7: The EPP_1_1 system data file (EPP_1_1.json)

```
{
  "HEADER COMMENTS":"The following data defines the Electric Power Plant system.",
  "System":{
        "Degraded System":{
            "ID": "EPP",
          "type":"equipment",
            "color": "#EB0F1E",
            "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Generator Set 1":{

      "ID":"GS_1",
                "VNTK":"null",
          "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": 1,
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "Air Filter 1":{
          "ID":"AIR_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
```

```
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Fuel System 1":{
          "ID":"FUEL_1",
              "type":"equipment",
          "relative position":[0,0,0],
          "VNTK": "null",
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Engine 1":{
          "ID":"ENG_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N1 1":{
          "ID":"N1_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
```

```
        },
        "N4 1":{
          "ID":"N4_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Generator 1":{
          "ID":"GEN_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N2 1":{
          "ID":"N2_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N3 1":{
          "ID":"N3_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
```

```
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K1 1":{
          "ID":"K1_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }}},

    "Generator Set 2":{

      "ID":"GS_2",
      "VNTK": "null",
          "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "Air Filter 2":{
          "ID":"AIR_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
```

```
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Fuel System 2":{
          "ID":"FUEL_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Engine 2":{
          "ID":"ENG_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N1 2":{
          "ID":"N1_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
```

```
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N4 2":{
          "ID":"N4_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Generator 2":{
          "ID":"GEN_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N2 2":{
          "ID":"N2_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N3 2":{
          "ID":"N3_2",
```

```
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K1 2":{
          "ID":"K1_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }}},

    "Power Distribution Unit":{

      "ID":"PDU_MAIN",
      "VNTK": "null",
          "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "PDU Control":{
          "ID":"PDU_CTRL",
          "VNTK": "null",
              "type":"equipment",
```

```
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "PDU Synchronizer":{
          "ID":"PDU_SYNCH",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "L1 Bus Bar":{
          "ID":"L1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "L2 Bus Bar":{
          "ID":"L2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
```

```
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "L3 Bus Bar":{
          "ID":"L3",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Neutral Bus Bar":{
          "ID":"NEUTRAL",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T1":{
          "ID":"T1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
```

```
        },
        "T2":{
          "ID":"T2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T3":{
          "ID":"T3",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T4":{
          "ID":"T4",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T5":{
          "ID":"T5",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
```

```
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T6":{
          "ID":"T6",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T7":{
          "ID":"T7",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T8":{
          "ID":"T8",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
```

```
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T9":{
          "ID":"T9",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T10":{
          "ID":"T10",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T11":{
          "ID":"T11",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
```

```
        "T12":{
          "ID":"T12",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K3":{
          "ID":"K3",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K4":{
          "ID":"K4",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K5":{
          "ID":"K5",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
```

```
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K6":{
          "ID":"K6",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J1":{
          "ID":"K7",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J2":{
          "ID":"J2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
```

```
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J3":{
          "ID":"J3",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J4":{
          "ID":"J4",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J5":{
          "ID":"J5",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
        }}},
```

```
855
856   "functions":"This is a placeholder for future work using subsystem and system functions underlying
        system capabilities.",
857
858   "capabilities":{
859     "Powers External Loads":[
860             {"Powers ECS & RS":{
861         "Begin Node":["EPP_X", "EPP_X"],
862         "End Node":["CC", "DD"],
863         "Has Path":[true],
864         "Comment":"Provides power to both ECS and RS"
865       }},
866       {"NOT POSSIBLE":{
867         "Begin Node":["EPP_X"],
868         "End Node":["FF"],
869         "Has Path":[false],
870         "Comment":"Cannot provide power to ECS or RS"
871       }},
872       {"Powers ECS Only":{
873         "Begin Node":["EPP_X"],
874         "End Node":["DD"],
875         "Has Path":[true],
876         "Comment":"Provides power to ECS only"
877       }},
878       {"Powers RS Only":{
879         "Begin Node":["EPP_X"],
880         "End Node":["CC"],
881         "Has Path":[true],
882         "Comment":"Provides power to RS only"
883       }}
884         ],
885     "R/T Short-Range Communications":[
886       {"R/T Data via J5 Cable":{
887         "Begin Node":["EPP_X"],
888         "End Node":["EE"],
889         "Has Path":[true],
890         "Comment":"R/T data with ECS via J5 cable"
891       }},
892       {"NOT POSSIBLE":{
893         "Begin Node":["EPP_X"],
894         "End Node":["PDU_CTRL"],
895         "Has Path":[false],
896         "Comment":"Cannot R/T short-range data communications"
897       }},
898       {"R/T Data via PDU Panel":{
899         "Begin Node":["EPP_X"],
900         "End Node":["PDU_CTRL"],
901         "Has Path":[true],
902         "Comment":"R/T data only via PDU control panel manual operation"
903       }}
904         ]
905   },
906
907   "Structure":{
908     "Admin Nodes":["AA","BB","CC","DD","EE","FF"],
909         "Terminal Nodes":["EPP_X", "EPP_XX"],
910     "Edges":{
```

```
      "EPP_X":["Degraded System"],
      "Degraded System":["AA"],
      "AA":["Generator Set 1", "Generator Set 2"],
      "Generator Set 1":["Air Filter 1"],
      "Air Filter 1":["Fuel System 1"],
      "Fuel System 1":["Engine 1"],
      "Engine 1":["N1 1"],
      "N1 1":["N4 1"],
      "N4 1":["Generator 1"],
      "Generator 1":["N2 1"],
      "N2 1":["N3 1"],
      "N3 1":["K1 1"],
      "K1 1":["BB"],
      "Generator Set 2":["Air Filter 2"],
      "Air Filter 2":["Fuel System 2"],
      "Fuel System 2":["Engine 2"],
      "Engine 2":["N1 2"],
      "N1 2":["N4 2"],
      "N4 2":["Generator 2"],
      "Generator 2":["N2 2"],
      "N2 2":["N3 2"],
      "N3 2":["K1 2"],
      "K1 2":["BB"],
      "BB":["Power Distribution Unit"],
      "Power Distribution Unit":["PDU Control"],
      "PDU Control":["PDU Synchronizer", "J5"],
      "J5":["EE"],
      "EE":["EPP_XX"],
      "PDU Synchronizer":["L1 Bus Bar"],
      "L1 Bus Bar":["L2 Bus Bar"],
      "L2 Bus Bar":["L3 Bus Bar"],
      "L3 Bus Bar":["Neutral Bus Bar"],
      "Neutral Bus Bar":["T1", "T10"],
      "T1":["T2"],
      "T2":["T3"],
      "T3":["T4"],
      "T4":["T5"],
      "T5":["T6"],
      "T6":["T7"],
      "T7":["T8"],
      "T8":["T9"],
      "T9":["K3"],
      "K3":["K4"],
      "K4":["K5"],
      "K5":["J1"],
      "J1":["J2"],
      "J2":["J3"],
      "J3":["CC"],
      "T10":["T11"],
      "T11":["T12"],
      "T12":["K6"],
      "K6":["J4"],
      "J4":["DD"],
            "CC":["FF"],
      "DD":["FF"],
      "FF":["EPP_XX"]
    }
```

```
968     }
969 }
```

Listing E.8: The EPP_1_2 system data file (EPP_1_2.json)

```
{
  "HEADER COMMENTS":"The following data defines the Electric Power Plant system.",
  "System":{
        "Degraded System":{
            "ID": "Degraded System",
          "type":"equipment",
            "color": "#EB0F1E",
            "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Generator Set 1":{

      "ID":"GS_1",
                "VNTK":"null",
          "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": 1,
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "Air Filter 1":{
          "ID":"AIR_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
```

```
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Fuel System 1":{
          "ID":"FUEL_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Engine 1":{
          "ID":"ENG_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N1 1":{
          "ID":"N1_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
```

```
        },
        "N4 1":{
          "ID":"N4_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Generator 1":{
          "ID":"GEN_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N2 1":{
          "ID":"N2_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N3 1":{
          "ID":"N3_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
```

```
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K1 1":{
          "ID":"K1_1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }}},

    "Generator Set 2":{

      "ID":"GS_2",
      "VNTK": "null",
          "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "Air Filter 2":{
          "ID":"AIR_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
```

```
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Fuel System 2":{
          "ID":"FUEL_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Engine 2":{
          "ID":"ENG_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N1 2":{
          "ID":"N1_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
```

```
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N4 2":{
          "ID":"N4_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Generator 2":{
          "ID":"GEN_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N2 2":{
          "ID":"N2_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "N3 2":{
          "ID":"N3_2",
```

```
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K1 2":{
          "ID":"K1_2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }}},

    "Power Distribution Unit":{

      "ID":"PDU_MAIN",
      "VNTK": "null",
          "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "PDU Control":{
          "ID":"PDU_CTRL",
          "VNTK": "null",
              "type":"equipment",
```

```
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "PDU Synchronizer":{
          "ID":"PDU_SYNCH",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "L1 Bus Bar":{
          "ID":"L1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "L2 Bus Bar":{
          "ID":"L2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
```

```
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "L3 Bus Bar":{
          "ID":"L3",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "Neutral Bus Bar":{
          "ID":"NEUTRAL",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T1":{
          "ID":"T1",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
```

```
        },
        "T2":{
          "ID":"T2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T3":{
          "ID":"T3",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T4":{
          "ID":"T4",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T5":{
          "ID":"T5",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
```

```
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T6":{
          "ID":"T6",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T7":{
          "ID":"T7",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T8":{
          "ID":"T8",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
```

```
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T9":{
          "ID":"T9",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T10":{
          "ID":"T10",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "T11":{
          "ID":"T11",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
```

```
        "T12":{
          "ID":"T12",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K3":{
          "ID":"K3",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K4":{
          "ID":"K4",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K5":{
          "ID":"K5",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
```

```
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "K6":{
          "ID":"K6",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J1":{
          "ID":"K7",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J2":{
          "ID":"J2",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
```

```
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J3":{
          "ID":"J3",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J4":{
          "ID":"J4",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
        "J5":{
          "ID":"J5",
          "VNTK": "null",
              "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
        }}},
```

```
855
856   "functions":"This is a placeholder for future work using subsystem and system functions underlying
        system capabilities.",
857
858   "capabilities":{
859     "Powers External Loads":[
860             {"Powers ECS & RS":{
861         "Begin Node":["EPP_X", "EPP_X"],
862         "End Node":["CC", "DD"],
863         "Has Path":[true],
864         "Comment":"Provides power to both ECS and RS"
865       }},
866       {"NOT POSSIBLE":{
867         "Begin Node":["EPP_X"],
868         "End Node":["FF"],
869         "Has Path":[false],
870         "Comment":"Cannot provide power to ECS or RS"
871       }},
872       {"Powers ECS Only":{
873         "Begin Node":["EPP_X"],
874         "End Node":["DD"],
875         "Has Path":[true],
876         "Comment":"Provides power to ECS only"
877       }},
878       {"Powers RS Only":{
879         "Begin Node":["EPP_X"],
880         "End Node":["CC"],
881         "Has Path":[true],
882         "Comment":"Provides power to RS only"
883       }}
884         ],
885     "R/T Short-Range Communications":[
886       {"R/T Data via J5 Cable":{
887         "Begin Node":["EPP_X"],
888         "End Node":["EE"],
889         "Has Path":[true],
890         "Comment":"R/T data with ECS via J5 cable"
891       }},
892             {"NOT POSSIBLE":{
893         "Begin Node":["EPP_X"],
894         "End Node":["PDU_CTRL"],
895         "Has Path":[false],
896         "Comment":"Cannot R/T short-range data communications"
897       }},
898       {"R/T Data via PDU Panel":{
899         "Begin Node":["EPP_X"],
900         "End Node":["PDU_CTRL"],
901         "Has Path":[true],
902         "Comment":"R/T data only via PDU control panel manual operation"
903       }}
904         ]
905   },
906
907   "Structure":{
908     "Admin Nodes":["AA","BB","CC","DD","EE","FF"],
909         "Terminal Nodes":["EPP_X", "EPP_XX"],
910     "Edges":{
```

```
      "EPP_X":["Degraded System"],
      "Degraded System":["AA"],
      "AA":["Generator Set 1", "Generator Set 2"],
      "Generator Set 1":["Air Filter 1"],
      "Air Filter 1":["Fuel System 1"],
      "Fuel System 1":["Engine 1"],
      "Engine 1":["N1 1"],
      "N1 1":["N4 1"],
      "N4 1":["Generator 1"],
      "Generator 1":["N2 1"],
      "N2 1":["N3 1"],
      "N3 1":["K1 1"],
      "K1 1":["BB"],
      "Generator Set 2":["Air Filter 2"],
      "Air Filter 2":["Fuel System 2"],
      "Fuel System 2":["Engine 2"],
      "Engine 2":["N1 2"],
      "N1 2":["N4 2"],
      "N4 2":["Generator 2"],
      "Generator 2":["N2 2"],
      "N2 2":["N3 2"],
      "N3 2":["K1 2"],
      "K1 2":["BB"],
      "BB":["Power Distribution Unit"],
      "Power Distribution Unit":["PDU Control"],
      "PDU Control":["PDU Synchronizer", "J5"],
      "J5":["EE"],
      "EE":["EPP_XX"],
      "PDU Synchronizer":["L1 Bus Bar"],
      "L1 Bus Bar":["L2 Bus Bar"],
      "L2 Bus Bar":["L3 Bus Bar"],
      "L3 Bus Bar":["Neutral Bus Bar"],
      "Neutral Bus Bar":["T1", "T10"],
      "T1":["T2"],
      "T2":["T3"],
      "T3":["T4"],
      "T4":["T5"],
      "T5":["T6"],
      "T6":["T7"],
      "T7":["T8"],
      "T8":["T9"],
      "T9":["K3"],
      "K3":["K4"],
      "K4":["K5"],
      "K5":["J1"],
      "J1":["J2"],
      "J2":["J3"],
      "J3":["CC"],
      "T10":["T11"],
      "T11":["T12"],
      "T12":["K6"],
      "K6":["J4"],
      "J4":["DD"],
            "CC":["FF"],
      "DD":["FF"],
      "FF":["EPP_XX"]
    }
```

```
968     }
969 }
```

Listing E.9: The small_sys system data file (small_sys.json)

```
{
    "HEADER COMMENTS":"The following data defines an example 'small system' used to develop the System
     class module for NuSCAP",
    "System":{
        "Small System":{
            "ID": "EPP_Main",
            "VNTK": "null",
            "type":"equipment",
            "color": "#EB0F1E",
            "thresholds":{
                "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": 22,
                "neutron fluence": 2002,
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": 0.999999
            }
        }
    },

    "Subsystems":{

        "Generator Set 1":{

            "ID":"GS1_Main",
            "type":"equipment",
            "relative position":[0,0,0],

            "thresholds":{
                "static overpressure": "inf",
                "dynamic pressure": 1,
                "windspeed": "inf",
                "thermal fluence": 3.1415926,
                "total dose": "inf",
                "neutron dose": 1E6,
                "neutron fluence": "inf",
                "gamma ray dose": 1,
                "gamma ray dose rate": "inf",
                "PD": 1
            },
            "Components":{
                "Air Filter 1":{
                    "ID":"AIR_1",
                    "type":"equipment",
                    "thresholds":{
                        "static overpressure": "inf",
                        "dynamic pressure": "inf",
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
```

```
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": 1},
                    "relative position":[0.75, 1.0, 1.25],

                    "Components":{
                        "Filter Element":{
                            "ID":"Filter_1",
                            "type":"equipment",
                            "relative position":[0,0,0],
                            "thresholds":{
                                "windspeed":50
                            }
                        }
                    }
                },
                "Fuel System 1":{
                    "ID":"FUEL_1",
                    "type":"equipment",
                    "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                        "dynamic pressure": "inf",
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": 1},
                    "Components":{
                        "Fuel Tank":
                        {
                            "ID": "Fuel Tank",
                            "type":"equipment",
                            "relative position":[0,0,0],
                            "thresholds":{
                                "total dose": 124
                                },
                            "Components":{
                                "Diesel":{
                                    "ID": "Diesel",
                                    "type":"equipment",
                                    "relative position":[0,0,0],
                                    "thresholds":{
                                        "thermal fluence": 12
                                        },
                                    "Components":{
                                        "Carbon":{
                                            "ID": "C",
                                            "type":"equipment",
                                            "relative position":[0,0,0],
                                            "thresholds":{
                                                "PD":0.963
                                            }
                                        }
```

```
                                    }
                                    }
                        }}
                    }
                }

            }
        },

        "Generator Set 2":{

            "ID":"GS2_Main",
            "type":"equipment",

            "thresholds":{
                "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": 0.995
            },
                    "relative position":[2.0, 3.5, 1.25],
            "Components":{
                "Air Filter 2":{
                    "ID":"AIR_2",
                    "type":"equipment",
                    "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                        "dynamic pressure": "inf",
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": 1},
                        "Components":{
                            "Filter Element 2":
                            {
                                "ID": "Filter_2",
                                "type":"equipment",
                                "relative position":[0,0,0],
                                "thresholds":{
                                    "thermal fluence": 6.25
                                    },
                                "Components":{
                                    "Paper":{
                                        "ID": "Paper",
                                        "type":"equipment",
                                        "relative position":[0,0,0],
```

```
                                        "thresholds":{
                                            "static overpressure": 1.02
                                            },
                                        "Components":{
                                            "Oxygen":{
                                                "ID": "O",
                                                "type":"equipment",
                                                "relative position":[0,0,0],
                                                "thresholds":{
                                                    "PD":0.1725
                                                }
                                        }
                                    }
                                }
                            }
                                        }
                }
            },
                "Fuel System 2":{
                    "ID":"FUEL_2",
                    "type":"equipment",
                    "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                        "dynamic pressure": "inf",
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": 1}
                }
                }
            }
        },

    "functions":"This is a placeholder for future work using subsystem and system functions underlying
     system capabilities.",

    "capabilities":{
        "Powers External Loads":[
            {"Power All Loads":{
                "Begin Node":["Small System_X"],
                "End Node":["FF"],
                "Has Path":[true],
                "Comment":"Provides power to both ECS and RS"
            }},
            {"NOT POSSIBLE":{
                "Begin Node":["Small System_X"],
                "End Node":["FF"],
                "Has Path":[false],
                "Comment":"Cannot provide power to ECS or RS"
            }},
            {"Power Load A":{
                "Begin Node":["Small System_X"],
```

```
                "End Node":["AA"],
                "Has Path":[false],
                "Comment":"Provides power ECS only"
            }},
            {"Power Load B":{
                "Begin Node":["Small System_X"],
                "End Node":["Small System"],
                "Has Path":[false],
                "Comment":"Provides power RS only"
            }}
        ],
        "R/T Short-Range Communications":[
                {"Coms Possible":{
                    "Begin Node":["Small System_X"],
                    "End Node":["BB"],
                    "Has Path":[true],
                    "Comment":"R/T data with ECS via J5 cable"
                }},
                {"NOT POSSIBLE":{
                    "Begin Node":["Small System_X"],
                    "End Node":["Small System_XX"],
                    "Has Path":[false],
                    "Comment":"Cannot R/T short-range data communications"
                }},
                {"Degraded Coms":{
                    "Begin Node":["Small System_X"],
                    "End Node":["DD"],
                    "Has Path":[true],
                    "Comment":"R/T data only via PDU control panel manual operation"
                }}
            ]
        },
    "Structure":{
        "Admin Nodes":["AA", "BB", "CC", "DD", "EE", "FF"],
        "Terminal Nodes":["Small System_X", "Small System_XX"],
        "Edges":{
            "Small System_X":["Small System"],
            "Small System":["AA"],
            "AA":["Generator Set 1",  "Generator Set 2"],
            "Generator Set 1":["Air Filter 1", "Fuel System 1"],
            "Air Filter 1":["Filter Element"],
            "Filter Element":["BB"],
            "Fuel System 1":["Fuel Tank"],
            "Fuel Tank":["Diesel"],
            "Diesel":["Carbon"],
            "Carbon":["CC"],
            "Generator Set 2":["Fuel System 2", "Air Filter 2"],
            "Fuel System 2":["EE"],
            "Air Filter 2":["Filter Element 2"],
            "Filter Element 2":["Paper"],
            "Paper":["Oxygen"],
            "Oxygen":["DD"],
            "BB":["FF"],
            "CC":["FF"],
            "DD":["FF"],
            "EE":["FF"],
            "FF":["Small System_XX"]
```

```
283             }
284         }
285         }
```

E.2.2.2 Scenario Data Files

Listing E.10: The Dysf_Scen scenario data file (Dysf_Scen.json)

```
{
    "HEADER COMMENTS":"The following data provides physical and temporal information governing weapon
    prameters and SOS layout for use by NuSCAP.",
  "Prefix":"C:/temp/",
  "Name":"Dysfunctional_System",
    "GIS and Weather Data":{
        "GIS Reference Datum": "WGS84",
        "Ground Zero Location": "53S KU 65818 09055",
        "Ground Zero Elevation": 1501,
        "DTG":"06 0815I AUG 1945",
        "Atmospheric Visibility [km]": 50
    },
    "Threat Weapon Data":{
        "Weapon Type":"General - Fission Only",
        "Fission Fraction":1,
        "Yield [kt]": 15,
        "HOB [m]": 580,
        "HOB sigma [m]": 0,
        "CEP [m]": 0,
        "Neutron Leakage Spectrum":{},
        "Photon Leakage Spectrum":{}
    },

    "Systems Data":{

        "Dysfunctional System":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 67 28",
                "Depth [m]": 0,
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
            "Heading [grid deg]": 0
            }
  },

        "ECS":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6322327335",
                "Depth [m]": 0,
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
            "Heading [grid deg]": 0
            }
        },

        "RS":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6322327353",
                "Depth [m]": 0,
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
            "Heading [grid deg]": 90
            }
```

```
        },
        "AMG":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
                "Depth [m]": 0,
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 1":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
                "Depth [m]": 0,
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 2":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
                "Depth [m]": 0,
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 3":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
                "Depth [m]": 0,
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 4":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
                "Depth [m]": 0,
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 5":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
                "Depth [m]": 0,
            "Elevation (MSL) [m]": 0,
```

```
                "R95 [km]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 6":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
                "Depth [m]": 0,
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
            "Heading [grid deg]": 0
            }

        }
    },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
     Laboratory",
  "Date":"6 DEC 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.11: The Scenario_Data scenario data file (Scenario_Data.json)

```
{
   "HEADER COMMENTS":"The following data provides physical and temporal information governing weapon
    prameters and SOS layout for use by NuSCAP.",
  "Prefix":"C:/temp/",
  "Name":"Example_Scenario",
    "GIS and Weather Data":{
        "GIS Reference Datum": "WGS84",
        "Ground Zero Location": "13S CT 63233 27350",
        "Ground Zero Elevation": 1501,
        "DTG":"16 1229Z JUL 1945",
        "Atmospheric Visibility [km]": 50
    },
    "Threat Weapon Data":{
        "Weapon Type":"General - Fission Only",
        "Fission Fraction":1,
        "Yield [kt]": 24.8,
        "HOB [m]": 30.48006,
        "HOB sigma [m]": 0,
        "CEP [m]": 0,
        "R95 [km]": 0,
        "Neutron Leakage Spectrum":{},
        "Photon Leakage Spectrum":{}
    },

    "Systems Data":{

        "Degraded System":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 632 273",
            "Elevation (MSL) [m]": 1504,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }
  },

        "ECS":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6322327335",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }
        },

        "RS":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6322327353",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 90
            }

        },
```

```
        "AMG":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 1":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 2":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 3":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 4":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 5":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
```

```
            }

        },
        "LS 6":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        }
    },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
      Laboratory",
  "Date":"5 DEC 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.12: The Scenario_Data.scdf scenario data file (Scenario_Data.scdf.json)

```
{
   "HEADER COMMENTS":"The following data provides physical and temporal information governing weapon
    prameters and SOS layout for use by NuSCAP.",
  "Prefix":"C:/temp/",
  "Name":"Example_Scenario",
    "GIS and Weather Data":{
        "GIS Reference Datum": "WGS84",
        "Ground Zero Location": "13S CT 63233 27350",
        "Ground Zero Elevation": 1501,
        "DTG":"16 1229Z JUL 1945",
        "Atmospheric Visibility [km]": 50
    },
    "Threat Weapon Data":{
        "Weapon Type":"General - Fission Only",
        "Fission Fraction":1,
        "Yield [kt]": 24.8,
        "HOB [m]": 30.48006,
        "HOB sigma [m]": 0,
        "CEP [m]": 0,
        "R95 [km]": 0,
        "Neutron Leakage Spectrum":{},
        "Photon Leakage Spectrum":{}
    },

    "Systems Data":{

        "Degraded System":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 6323 2734",
            "Elevation (MSL) [m]": 1504,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }
  },

        "ECS":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63223 27335",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }
        },

        "EPP":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63223 27353",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 90
            }

        },
```

```
        "AMG":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63243 27343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 1":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63243 27343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 2":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63243 27343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 3":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63243 27343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 4":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63243 27343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 5":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63243 27343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
```

```
            }

        },
        "LS 6":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63243 27343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        }
    },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National Laboratory",
  "Date":"5 DEC 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.13: The SS_Scenario_Data scenario data file (SS_Scenario_Data.scdf.json)

```
{
   "HEADER COMMENTS":"The following data provides physical and temporal information governing weapon
    prameters and SOS layout for use by NuSCAP.",
  "Prefix":"C:/temp/",
  "Name":"Example_Scenario",
    "GIS and Weather Data":{
        "GIS Reference Datum": "WGS84",
        "Ground Zero Location": "13S CT 63233 27350",
        "Ground Zero Elevation": 1501,
        "DTG":"16 1229Z JUL 1945",
        "Atmospheric Visibility [km]": 50
    },
    "Threat Weapon Data":{
        "Weapon Type":"General - Fission Only",
        "Fission Fraction":1,
        "Yield [kt]": 24.8,
        "HOB [m]": 30.48006,
        "HOB sigma [m]": 0,
        "CEP [m]": 0,
        "R95 [km]": 0,
        "Neutron Leakage Spectrum":{},
        "Photon Leakage Spectrum":{}
    },

    "Systems Data":{

        "EPP":{
          "GIS Data":{
            "Location (MGRS)": "13S C 63243 27343",
            "Elevation (MSL) [m]": 1504,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }
  },

        "Small System":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6322327335",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }
        },

        "RS":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6322327353",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 90
            }

        },
```

```
        "AMG":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 1":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 2":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 3":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 4":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        },
        "LS 5":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
```

```
            }

        },
        "LS 6":{
          "GIS Data":{
            "Location (MGRS)": "13SCT6324327343",
            "Elevation (MSL) [m]": 0,
                "R95 [km]": 0,
                "Depth [m]": 0,
            "Heading [grid deg]": 0
            }

        }
    },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National Laboratory",
  "Date":"5 DEC 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

E.2.3 SOS Test Data

E.2.3.1 SOS Data Files

Listing E.14: The Degraded system-of-systems data file (Degraded.sosdf.json)

```
{
    "HEADER COMMENTS":"The following data defines the SOS for analysis.",
    "System of Systems":{
        "Degraded SOS":{
            "ID":"Degraded SOS"
        }
    },

    "Systems":{
        "System 1":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Degraded_SDFs/SYS_1.sdf.
    json"
        },
        "System 2":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Degraded_SDFs/SYS_2.sdf.
    json"
        },
        "System 3":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Degraded_SDFs/SYS_3.sdf.
    json"
        },
        "System 5.1":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Degraded_SDFs/SYS_5_1.
    sdf.json"
        },
        "System 5.2":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Degraded_SDFs/SYS_5_2.
    sdf.json"
        }
    },

    "SOS capabilities":{
        "Power Core Systems":[
            {"Power Systems 1, 2 and 3":{
        "Begin Node":["X", "X", "AA_3", "CC_3"],
        "End Node":["AA_3", "CC_3", "AA_1", "CC_2"],
        "Has Path":[true, true, true, true],
        "Comment":"Powers all core systems"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X", "X"],
        "End Node":["CC_3", "AA_3"],
        "Has Path":[false, false],
        "Comment":"Cannot power core systems"
        }
            },
            {"Power System 1 and 3 ONLY":{
        "Begin Node":["X_3", "X_3"],
        "End Node":["CC_3", "AA_3"],
        "Has Path":[false, true],
        "Comment":"Power System 1 and 3 ONLY"
```

```
        }
            },
            {"Power System 2 and 3 ONLY":{
        "Begin Node":["X_3", "X_3"],
        "End Node":["AA_3", "CC_3"],
        "Has Path":[false, true],
        "Comment":"Power System 2 and 3 ONLY"
        }
            }
        ],
        "Control/Monitor Power Generation":[
            {"Control/Monitor via Cable and Control Panel":{
                "Begin Node":["X_1","X_1", "X_3"],
                "End Node":["BB_1", "BB_3_1", "BB_3"],
                "Has Path":[true, true, true],
                "Comment":"Control Power Generation via cable and control panel"
                }
            },
            {"NOT POSSIBLE":{
                "Begin Node":["X_1"],
                "End Node":["BB_3"],
                "Has Path":[false],
                "Comment":"Cannot control Power Generation"
                }
            },
            {"Control via Control Panel ONLY":{
                "Begin Node":["X_1", "X_1"],
                "End Node":["BB_3", "BB_3_1"],
                "Has Path":[false, true],
                "Comment":"Control Power Generation via control panel ONLY"
                }
            }
        ],
        "Control/Monitor System 2":[
            {"Control/Monitor via Cable":{
                "Begin Node":["X_1","X_2"],
                "End Node":["DD_1","DD_2"],
                "Has Path":[true, true],
                "Comment":"Controls System 2 via cable"
                }
            },
            {"NOT POSSIBLE":{
                "Begin Node":["X_1"],
                "End Node":["DD_2"],
                "Has Path":[false],
                "Comment":"Cannot control System 2"
                }
            }
        ],
        "Control/Monitor Weapon System 5.1":[
            {"Control/Monitor via Optical Fiber or VHF Radio":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2a", "EE_1_1"],
        "Has Path":[true, true],
        "Comment":"Control/monitor System 5.1 via OF or VHF Radio"
        }
            },
```

```
            {"NOT POSSIBLE":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2a", "EE_1_1"],
        "Has Path":[false, false],
        "Comment":"Cannot control/monitor System 5.1"
        }
            },
            {"Control/Monitor via VHF Radio ONLY":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2a", "EE_1_1"],
        "Has Path":[false, true],
        "Comment":"Control/monitor System 5.1 via VHF Radio ONLY"
        }
            },
            {"Control/Monitor via Optical Fiber ONLY":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_1","EE_1_2a"],
        "Has Path":[false, true],
        "Comment":"Control/monitor System 5.1 via OF ONLY"
        }
            }
        ],
        "Control/Monitor Weapon System 5.2":[
            {"Control/Monitor via Optical Fiber or VHF Radio":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2b", "EE_1_1"],
        "Has Path":[true, true],
        "Comment":"Control/monitor System 5.2 via OF or VHF Radio"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2b", "EE_1_1"],
        "Has Path":[false, false],
        "Comment":"Cannot control/monitor System 5.2"
        }
            },
            {"Control/Monitor via VHF Radio ONLY":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2b", "EE_1_1"],
        "Has Path":[false, true],
        "Comment":"Control/monitor System 5.2 via VHF Radio ONLY"
        }
            },
            {"Control/Monitor via Optical Fiber ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_1","EE_1_2b"],
        "Has Path":[false, true],
        "Comment":"Control/monitor System 5.2 via OF ONLY"
        }
            }
        ]
    },

    "SOS Structure":{
        "Admin Nodes":[],
        "Terminal Nodes":["X", "XX"],
```

```
        "Edges":{
            "X":["X_3"],
            "XX_5_1":["XX"],
            "XX_5_2":["XX"]
        },
        "Capability Edges":{
            "AA_3":["AA_1"],
            "BB_1_1":["BB_3_1"],
            "BB_3_1":["BB_1_1"],
            "BB_1":["BB_3"],
            "BB_3":["BB_1"],
            "CC_3":["CC_2"],
            "DD_1":["DD_2"],
            "DD_2":["DD_1"],
            "EE_1_1":["EE_5_1_1", "EE_5_2_1"],
            "EE_1_2a":["EE_5_1_2"],
            "EE_1_2b":["EE_5_2_2"],
            "EE_5_1_2":["EE_1_2a"],
            "EE_5_2_2":["EE_1_2b"],
            "EE_5_1_1":["EE_1_1"],
            "EE_5_2_1":["EE_1_1"]
        }
    }

}
```

Listing E.15: The Demo system-of-systems data file (Demo.sosdf.json)

```
{
    "HEADER COMMENTS":"The following data defines the SOS for analysis.",
    "System of Systems":{
        "Demo SOS":{
            "ID":"Demo SOS"
        }
    },

    "Systems":{
        "System 1":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Demo_SDFs/SYS_1.sdf.json
    "
        },
        "System 2":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Demo_SDFs/SYS_2.sdf.json
    "
        },
        "System 3":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Demo_SDFs/SYS_3.sdf.json
    "
        },
        "System 5.1":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Demo_SDFs/SYS_5_1.sdf.
    json"
        },
        "System 5.2":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Demo_SDFs/SYS_5_2.sdf.
    json"
        }
    },

    "SOS capabilities":{
        "Power Core Systems":[
            {"Power Systems 1, 2 and 3":{
        "Begin Node":["X", "X", "X", "AA_3", "CC_3"],
        "End Node":["XX_3", "AA_3", "CC_3", "AA_1", "CC_2"],
        "Has Path":[true],
        "Comment":"Powers all core systems"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_3", "X_3"],
        "End Node":["CC_2", "AA_1"],
        "Has Path":[false],
        "Comment":"Cannot power core systems"
        }
            },
            {"Power System 1 and 3 ONLY":{
        "Begin Node":["X_3"],
        "End Node":["CC_2"],
        "Has Path":[false],
        "Comment":"Power System 1 and 3 ONLY"
        }
            },
            {"Power System 2 and 3 ONLY":{
        "Begin Node":["X_3"],
```

```
        "End Node":["AA_1"],
        "Has Path":[false],
        "Comment":"Power System 2 and 3 ONLY"
        }
            }
        ],
        "Control/Monitor Power Generation":[
            {"Control/Monitor via Cable or Control Panel":{
                "Begin Node":["X_1","BB_1_1", "BB_1"],
                "End Node":["BB_1", "BB_3_1", "BB_3"],
                "Has Path":[ true],
                "Comment":"Control Power Generation via cable or control panel"
                }
            },
            {"NOT POSSIBLE":{
                "Begin Node":["X_1"],
                "End Node":["BB_3"],
                "Has Path":[ false],
                "Comment":"Cannot control Power Generation"
                }
            },
            {"Control via Control Panel ONLY":{
                "Begin Node":["BB_1"],
                "End Node":["BB_3"],
                "Has Path":[ false],
                "Comment":"Control Power Generation via control panel ONLY"
                }
            }
        ],
        "Control/Monitor System 2":[
            {"Control/Monitor via Cable":{
                "Begin Node":["X_1"],
                "End Node":["DD_2"],
                "Has Path":[ true],
                "Comment":"Controls System 2 via cable"
                }
            },
            {"NOT POSSIBLE":{
                "Begin Node":["X_1"],
                "End Node":["DD_2"],
                "Has Path":[ false],
                "Comment":"Cannot control System 2"
                }
            }
        ],
        "Control/Monitor Weapon System 5.1":[
            {"Control/Monitor via Optical Fiber or VHF Radio":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_5_1_1","EE_5_1_2"],
        "Has Path":[true],
        "Comment":"Control/monitor System 5.1 via OF or VHF Radio"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_5_1_1","EE_5_1_2"],
        "Has Path":[false],
```

```
        "Comment":"Cannot control/monitor System 5.1"
        }
            },
            {"Control/Monitor via VHF Radio ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_5_1_2"],
        "Has Path":[false],
        "Comment":"Control/monitor System 5.1 via VHF Radio ONLY"
        }
            },
            {"Power System 2 and 3 ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_5_1_1"],
        "Has Path":[false],
        "Comment":"Control/monitor System 5.1 via VHF Radio ONLY"
        }
            }
        ],
        "Control/Monitor Weapon System 5.2":[
            {"Control/Monitor via Optical Fiber or VHF Radio":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_5_2_1","EE_5_2_2"],
        "Has Path":[true],
        "Comment":"Control/monitor System 5.2 via OF or VHF Radio"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_5_2_1","EE_5_2_2"],
        "Has Path":[false],
        "Comment":"Cannot control/monitor System 5.2"
        }
            },
            {"Control/Monitor via VHF Radio ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_5_2_2"],
        "Has Path":[false],
        "Comment":"Control/monitor System 5.2 via VHF Radio ONLY"
        }
            },
            {"Power System 2 and 3 ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_5_2_1"],
        "Has Path":[false],
        "Comment":"Control/monitor System 5.2 via VHF Radio ONLY"
        }
            }
        ]
    },

    "SOS Structure":{
        "Admin Nodes":[],
        "Terminal Nodes":["X", "XX"],
        "Edges":{
            "X":["X_3"],
            "XX_3":["X_2"],
            "XX_2":["X_1"],
```

```
            "XX_1":["X_5_1","X_5_2"],
            "XX_5_1":["XX"],
            "XX_5_2":["XX"]
        },
        "Capability Edges":{
            "AA_3":["AA_1"],
            "BB_1_1":["BB_3_1"],
            "BB_3_1":["BB_1_1"],
            "BB_1":["BB_3"],
            "BB_3":["BB_1"],
            "CC_3":["CC_2"],
            "DD_1":["DD_2"],
            "DD_2":["DD_1"],
            "EE_1_1":["EE_5_1_1", "EE_5_2_1"],
            "EE_1_2a":["EE_5_1_2"],
            "EE_1_2b":["EE_5_2_2"],
            "EE_5_1_2":["EE_1_2a"],
            "EE_5_2_2":["EE_1_2b"],
            "EE_5_1_1":["EE_1_1"],
            "EE_5_2_1":["EE_1_1"]
        }
    }

}
```

Listing E.16: The Errors system-of-systems data file (Errors.sosdf.json)

```
{
    "HEADER COMMENTS":"The following data defines the SOS for analysis.",
    "System of Systems":{
        "Erroneous SOS":{
            "ID":"Erroneous SOS"
        }
    },

    "Systems":{
        "System 1":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Errors_SDFs/SYS_1.sdf.
    json"
        },
        "System 2":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Errors_SDFs/SYS_2.sdf.
    json"
        },
        "System 3":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Errors_SDFs/SYS_3.sdf.
    json"
        },
        "System 5.1":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Errors_SDFs/SYS_5_1.sdf.
    json"
        },
        "System 5.2":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Errors_SDFs/SYS_5_2.sdf.
    json"
        }
    },

    "SOS capabilities":{
        "Power Core Systems":[
            {"Power Systems 1, 2 and 3":{
        "Begin Node":["X", "X", "AA_3", "CC_3"],
        "End Node":["AA_3", "CC_3", "AA_1", "CC_2"],
        "Has Path":[true, true, true, true],
        "Comment":"Powers all core systems"
        }
            },
            {"BOB":{
        "Begin Node":["X", "X"],
        "End Node":["CC_3", "AA_3"],
        "Has Path":[false, false],
        "Comment":"Cannot power core systems"
        }
            },
            {"Power System 1 and 3 ONLY":{
        "Begin Node":["X_3", "X_3"],
        "End Node":["CC_3", "AA_3"],
        "Has Path":[false, true],
        "Comment":"Power System 1 and 3 ONLY"
        }
            },
            {"Power System 2 and 3 ONLY":{
        "Begin Node":["X_3", "X_3"],
```

```
        "End Node":["AA_3", "CC_3"],
        "Has Path":[false, true],
        "Comment":"Power System 2 and 3 ONLY"
        }
            }
        ],
        "Control/Monitor Power Generation":[
            {"Control/Monitor via Cable and Control Panel":{
                "Begin Node":["X_1","X_1", "X_3"],
                "End Node":["BB_1", "BB_3_1", "BB_3"],
                "Has Path":[true, true, true],
                "Comment":"Control Power Generation via cable and control panel"
                }
            },
            {"NOT POSSIBLE":{
                "Begin Node":["X_1"],
                "End Node":["BB_3"],
                "Has Path":[false],
                "Comment":"Cannot control Power Generation"
                }
            },
            {"Control via Control Panel ONLY":{
                "Begin Node":["X_1", "X_1"],
                "End Node":["BB_3", "BB_3_1"],
                "Has Path":[false, true],
                "Comment":"Control Power Generation via control panel ONLY"
                }
            }
        ],
        "Control/Monitor System 2":[
            {"Control/Monitor via Cable":{
                "Begin Node":["X_1","X_2"],
                "End Node":["DD_1","DD_2"],
                "Has Path":[true, true],
                "Comment":"Controls System 2 via cable"
                }
            },
            {"NOT POSSIBLE":{
                "Begin Node":["X_1"],
                "End Node":["DD_2"],
                "Has Path":[false],
                "Comment":"Cannot control System 2"
                }
            }
        ],
        "Control/Monitor Weapon System 5.1":[
            {"Control/Monitor via Optical Fiber or VHF Radio":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2a", "EE_1_1"],
        "Has Path":[true, true],
        "Comment":"Control/monitor System 5.1 via OF or VHF Radio"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2a", "EE_1_1"],
        "Has Path":[false, false],
```

```
        "Comment":"Cannot control/monitor System 5.1"
        }
            },
            {"Control/Monitor via VHF Radio ONLY":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2a", "EE_1_1"],
        "Has Path":[false, true],
        "Comment":"Control/monitor System 5.1 via VHF Radio ONLY"
        }
            },
            {"Control/Monitor via Optical Fiber ONLY":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_1","EE_1_2a"],
        "Has Path":[false, true],
        "Comment":"Control/monitor System 5.1 via OF ONLY"
        }
            }
        ],
        "Control/Monitor Weapon System 5.2":[
            {"Control/Monitor via Optical Fiber or VHF Radio":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2b", "EE_1_1"],
        "Has Path":[true, true],
        "Comment":"Control/monitor System 5.2 via OF or VHF Radio"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2b", "EE_1_1"],
        "Has Path":[false, false],
        "Comment":"Cannot control/monitor System 5.2"
        }
            },
            {"Control/Monitor via VHF Radio ONLY":{
        "Begin Node":["X_1","X_1"],
        "End Node":["EE_1_2b", "EE_1_1"],
        "Has Path":[false, true],
        "Comment":"Control/monitor System 5.2 via VHF Radio ONLY"
        }
            },
            {"Control/Monitor via Optical Fiber ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_1","EE_1_2b"],
        "Has Path":[false, true],
        "Comment":"Control/monitor System 5.2 via OF ONLY"
        }
            }
        ]
    },

    "SOS Structure":{
        "Admin Nodes":[],
        "Terminal Nodes":["X", "XX"],
        "Edges":{
            "X":["X_3"],
            "XX_5_1":["XX"],
            "XX_5_2":["XX"]
```

```
        },
        "Capability Edges":{
            "AA_3":["AA_1"],
            "BB_1_1":["BB_3_1"],
            "BB_3_1":["BB_1_1"],
            "BB_1":["BB_3"],
            "BB_3":["BB_1"],
            "CC_3":["CC_2"],
            "DD_1":["DD_2"],
            "DD_2":["DD_1"],
            "EE_1_1":["EE_5_1_1", "EE_5_2_1"],
            "EE_1_2a":["EE_5_1_2"],
            "EE_1_2b":["EE_5_2_2"],
            "EE_5_1_2":["EE_1_2a"],
            "EE_5_2_2":["EE_1_2b"],
            "EE_5_1_1":["EE_1_1"],
            "EE_5_2_1":["EE_1_1"]
        }
    }

}
```

E.2.3.2 Scenario Data Files

Listing E.17: The Degraded analytical scenario data file (Degraded.scdf.json)

```
{
    "HEADER COMMENTS":"The following data provides physical and temporal information governing weapon prameters and SOS layout for use by NuSCAP.",
  "Prefix":"C:/temp/Demo_SOS/",
  "Name":"Degraded_Scenario_(Bin_3)",
    "MCNP path":"C:/MCNP62/MCNP_CODE/bin/mcnp6",
    "MCNP datapath":"C:/MCNP62/MCNP_DATA",
    "MCNP threads":8,
    "SNEC path":"C:/Users/339528/Documents/Git/NuSCAP/NuSCAP/JSL/JSL_5.6/Dist_2/Combined_JSL_5.6_Distro/Java Tools for Windows/WebMultipleEffects",
    "GIS and Weather Data":{
        "GIS Reference Datum": "WGS84",
        "Ground Zero Location": "13S CT 63233 27350",
        "Ground Zero Elevation (MSL) [m]": 1309,
        "DTG":"16 1229Z JUL 1945",
        "Atmospheric Visibility [km]": 50
    },
    "Threat Weapon Data":{
        "Weapon Type":"General - Fission Only",
        "Fission Fraction": 1,
        "Yield [kt]": 24.8,
        "HOB [m]": 30.48006,
        "HOB sigma [m]": 0,
        "CEP [m]": 0,
        "NPS":1E3,
        "Neutron Leakage Spectrum":{
            "si option":"H",
            "neutron yield [mol/kt]": 0.264,
            "energy bins [MeV]":[
                1.00E-16, 1.00E-11, 5.00E-10, 2.00E-9, 5.00E-9, 1.00E-8, 1.45E-8, 2.10E-8,
                3.00E-8, 4.00E-8, 5.00E-8, 7.00E-8, 1.00E-7, 1.25E-7, 1.50E-7, 1.84E-7,
                2.25E-7, 2.75E-7, 3.25E-7, 3.67E-7, 4.14E-7, 5.00E-7, 5.32E-7, 6.25E-7,
                6.83E-7, 8.00E-7, 8.67E-7, 1.00E-6, 1.04E-6, 1.08E-6, 1.13E-6, 1.30E-6,
                1.45E-6, 1.86E-6, 2.38E-6, 3.06E-6, 3.93E-6, 5.04E-6, 6.48E-6, 8.32E-6,
                1.07E-5, 1.37E-5, 1.76E-5, 2.26E-5, 2.90E-5, 3.73E-5, 4.79E-5, 6.14E-5,
                7.89E-5, 1.01E-4, 1.30E-4, 1.67E-4, 2.14E-4, 2.75E-4, 3.54E-4, 4.54E-4,
                5.83E-4, 7.49E-4, 9.61E-4, 1.23E-3, 1.58E-3, 2.03E-3, 2.25E-3, 2.49E-3,
                2.61E-3, 2.75E-3, 3.04E-3, 3.35E-3, 3.71E-3, 4.31E-3, 5.53E-3, 7.10E-3,
                9.12E-3, 1.06E-2, 1.17E-2, 1.50E-2, 1.93E-2, 2.19E-2, 2.36E-2, 2.42E-2,
                2.48E-2, 2.61E-2, 2.70E-2, 2.85E-2, 3.18E-2, 3.43E-2, 4.09E-2, 4.63E-2,
                5.25E-2, 5.66E-2, 6.74E-2, 7.20E-2, 7.95E-2, 8.25E-2, 8.65E-2, 9.80E-2,
                1.11E-1, 1.17E-1, 1.23E-1, 1.29E-1, 1.36E-1, 1.43E-1, 1.50E-1, 1.58E-1,
                1.66E-1, 1.74E-1, 1.83E-1, 1.93E-1, 2.02E-1, 2.13E-1, 2.24E-1, 2.35E-1,
                2.47E-1, 2.73E-1, 2.87E-1, 2.95E-1, 2.97E-1, 2.98E-1, 3.02E-1, 3.34E-1,
                3.69E-1, 3.88E-1, 4.08E-1, 4.50E-1, 4.98E-1, 5.23E-1, 5.50E-1, 5.78E-1,
                6.08E-1, 6.39E-1, 6.72E-1, 7.07E-1, 7.43E-1, 7.81E-1, 8.21E-1, 8.63E-1,
                9.07E-1, 9.62E-1, 1.00, 1.11, 1.16, 1.22, 1.29, 1.35, 1.42, 1.50, 1.57,
                1.65, 1.74, 1.83, 1.92, 2.02, 2.12, 2.23, 2.31, 2.35, 2.37, 2.39, 2.47,
                2.59, 2.73, 2.87, 3.01, 3.17, 3.33, 3.68, 4.07, 4.49, 4.72, 4.97, 5.23,
                5.49, 5.77, 6.07, 6.38, 6.59, 6.70, 7.05, 7.41, 7.79, 8.19, 8.61, 9.05,
                9.51, 10.0, 10.5, 11.1, 11.6, 12.2, 12.5, 12.8, 13.5, 13.8, 14.2, 14.6,
                14.9, 15.7, 16.5, 16.9, 17.3, 20.0
            ],
```

```
            "sp option":"D",
            "probability [mol/MeV-kt]":[
                0, 1.00E-9, 2.04E-11, 6.67E-12, 3.33E-12, 2.00E-12, 2.22E-12, 1.78, 2.75, 3.07,
                5.95, 12.7, 15.5, 22.8, 31.9, 23.9, 46.0, 44.1, 59.2, 75.7, 64.2, 80.9, 99.7,
                1.00E2, 111, 139, 159, 170, 174, 197, 182, 218, 235, 271, 339, 410, 512, 616,
                748, 886, 1.04E3, 1.19E3, 1.34E3, 1.45E3, 1.52E3, 1.54E3, 1.48E3, 1.36E3,
                1.19E3, 996, 794, 614, 462, 334, 228, 141, 74.8, 33.3, 12.4, 3.84, 1.02,
                2.26E-1, 7.77E-2, 6.15E-2, 4.43E-2, 3.12E-2, 3.34E-2, 2.52E-2, 2.17E-2, 1.67E-2,
                1.40E-2, 1.08E-2, 8.59E-3, 6.76E-3, 5.36E-3, 5.23E-3, 4.57E-3, 4.19E-3, 4.43E-3,
                4.53E-3, 4.36E-3, 4.87E-3, 4.89E-3, 1.20E-3, 1.42E-3, 1.31E-3, 1.13E-3, 1.92E-3,
                1.76E-3, 1.65E-3, 1.79E-3, 2.17E-3, 1.70E-3, 1.30E-3, 5.97E-4, 8.85E-4, 1.16E-3,
                1.33E-3, 1.01E-3, 1.55E-3, 1.44E-3, 8.63E-4, 6.13E-4, 7.12E-4, 8.11E-4, 9.41E-4,
                1.04E-3, 9.16E-4, 7.07E-4, 6.42E-4, 7.43E-4, 7.87E-4, 8.82E-4, 9.11E-4, 7.03E-4,
                7.30E-4, 8.21E-4, 6.02E-4, 7.36E-4, 6.93E-4, 7.46E-4, 6.05E-4, 6.61E-4, 4.35E-4,
                6.21E-4, 6.59E-4, 6.69E-4, 6.71E-4, 7.90E-4, 7.04E-4, 6.70E-4, 6.48E-4, 6.64E-4,
                6.06E-4, 5.40E-4, 5.52E-4, 4.98E-4, 4.85E-4, 3.69E-4, 3.88E-4, 4.68E-4, 4.65E-4,
                4.67E-4, 3.91E-4, 4.46E-4, 4.48E-4, 4.17E-4, 3.76E-4, 4.15E-4, 3.74E-4, 3.37E-4,
                3.39E-4, 3.51E-4, 3.54E-4, 3.70E-4, 4.51E-4, 4.31E-4, 4.45E-4, 3.63E-4, 2.79E-4,
                2.60E-4, 2.27E-4, 1.84E-4, 1.83E-4, 1.16E-4, 9.70E-5, 9.33E-5, 8.52E-5, 1.00E-4,
                9.49E-5, 7.73E-5, 6.52E-5, 5.32E-5, 5.05E-5, 3.92E-5, 3.45E-5, 3.18E-5, 3.03E-5,
                1.79E-5, 1.26E-5, 9.18E-6, 1.02E-5, 6.88E-6, 5.81E-6, 3.17E-6, 2.07E-6, 1.75E-6,
                1.29E-6, 9.17E-7, 3.68E-7, 4.17E-7, 1.96E-7, 8.11E-8, 2.01E-7, 1.63E-7, 2.43E-7,
                1.05E-7, 3.11E-8, 6.58E-8, 0, 2.86E-8
            ],
            "reference":"LA-UR-13-26113, Table 6"
        },
        "Neutron Response Functions":{
            "Human":{
                "Energy [MeV]":[
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293     "Developer Title":"Major, U.S. Army",
294     "Developer Organization":"Radiation Transport Applications Group, Los Alamos National Laboratory",
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Listing E.18: The Demo analytical scenario data file (Demo.scdf.json)

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                        3.21528E-03, 3.61954E-03, 4.06547E-03, 4.58726E-03, 5.22228E-03, 5.83754E-03,
                        6.49984E-03, 7.30252E-03, 8.18355E-03, 9.18417E-03, 1.02944E-02, 1.15055E-02,
                        1.28715E-02, 1.43322E-02, 1.63567E-02, 1.77608E-02, 1.96045E-02, 2.16808E-02,
                        2.30574E-02, 2.40674E-02, 2.58766E-02, 2.95862E-02, 2.53388E-02, 1.44824E-01,
                        6.03347E-02, 4.99138E-02, 2.51383E-02, 3.30996E-01, 9.39793E-01, 5.87161E-01,
                        5.27088E-01, 5.51634E-01, 5.74569E-01, 8.18293E-01, 6.84671E-01, 5.99507E-01,
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            "si option":"H",
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                1.340, 1.500, 1.660, 2.000, 2.500, 3.000, 3.500, 4.000, 4.500, 5.000, 5.500,
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            "sp option":"D",
            "probability [mol/MeV-kt]":[
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                5.85E-2, 8.00E-2, 7.46E-2, 7.76E-2, 5.83E-2, 5.48E-2, 6.76E-2, 3.85E-1, 7.32E-2,
                4.00E-2, 3.35E-2, 3.08E-2, 2.34E-2, 1.90E-2, 2.07E-2, 1.84E-2, 1.66E-2, 1.59E-2,
                7.66E-3, 4.25E-3, 5.43E-3, 2.58E-3, 6.75E-4, 5.44E-4, 4.29E-4, 3.55E-4, 3.50E-4,
                1.20E-4, 9.42E-4, 2.79E-5, 9.69E-6, 3.38E-8, 1.67E-13, 0
            ],
            "reference":"LA-UR-13-26113, Table 7"
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            "Energy [MeV]":[
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                0.65, 0.7, 0.8, 1.0, 1.4, 1.8, 2.2, 2.6, 2.8, 3.25, 3.75, 4.25, 4.75, 5.0, 5.25,
                5.75, 6.25, 6.75, 7.5, 9.0, 11.0, 13.0, 15.0
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                8.78E-7, 9.85E-7, 1.08E-6, 1.11E-6, 1.27E-6, 1.36E-6, 1.44E-6, 1.52E-6, 1.68E-6,
                1.98E-6, 2.51E-6, 2.99E-6, 3.42E-6, 3.82E-6, 4.01E-6, 4.41E-6, 4.83E-6, 5.23E-6,
                5.6E-6, 5.8E-6, 6.01E-6, 6.37E-6, 6.74E-6, 7.11E-6, 7.66E-6, 8.77E-6, 1.03E-5,
                1.18E-5, 1.33E-5
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            "reference":"ANSI/ANS-6.1.1-1977, Table 3"
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            "Equipment":{
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    "values":"3.4350364E-10  14  -5  -6",
    "reference":"MatMCNP, Russ DePriest"
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        }
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            "Elevation (MSL) [m]": 1501,
                "R95 [km]": 0,
                "Depth [m]":0,
            "Heading [grid deg]": 0
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          "GIS Data":{
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            "Elevation (MSL) [m]": 1501,
                "R95 [km]": 0,
                "Depth [m]":0,
            "Heading [grid deg]": 0
            }
        },

        "System 2":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63233 27353",
            "Elevation (MSL) [m]":1501,
                "R95 [km]": 0,
                "Depth [m]":0,
            "Heading [grid deg]": 90
            }

        },
        "System 5.1":{
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          "GIS Data":{
            "Location (MGRS)": "13S CT 624 282",
            "Elevation (MSL) [m]": 1488,
                "R95 [km]": 0,
                "Depth [m]":0,
            "Heading [grid deg]": 314
            }

        },
        "System 5.2":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63917 28331",
            "Elevation (MSL) [m]": 1521,
                "R95 [km]": 0,
                "Depth [m]":0,
            "Heading [grid deg]": 34
            }

        }
    },

    "Transport Materials":{
        "Surface":{
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            "Density [g/cm^3]":1.52,
            "Composition":{
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                "8017":-0.000207,
                "8018":-0.001185,
                "11023":-0.006140,
                "12000":-0.013304,
                "13027":-0.068564,
                "14000":-0.271180,
                "19000":-0.014327,
                "20000":-0.051166,
                "22000":-0.004604,
                "25055":-0.000715,
                "26000":-0.056285
            },
            "Notes":"PNNL-15870, Rev. 2"
        },
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            "Density [g/cm^3]":0.001205,
            "Composition":{
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                "7014":-0.752316,
                "7015":-0.002944,
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                "8017":-0.000094,
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            "Notes":"PNNL-15870, Rev. 2"
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    },
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  "Developer Name":"R. Boone Gilbreath",
    "Developer Title":"Major, U.S. Army",
    "Developer Organization":"Radiation Transport Applications Group, Los Alamos National Laboratory",

  "Maintainer":"R. Boone Gilbreath",
    "Maintainer Title":"Major, U.S. Army",
    "Maintainer Organization":"Radiation Transport Applications Group, Los Alamos National Laboratory"
}
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Listing E.19: The Errors analytical scenario data file (Errors.scdf.json)

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{
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    prameters and SOS layout for use by NuSCAP.",
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  "Name":"Erroneous",
    "GIS and Weather Data":{
        "GIS Reference Datum": "WGS84",
        "Ground Zero Location": "13S CT 63233 27350",
        "Ground Zero Elevation (MSL) [m]": 1309,
        "DTG":"16 1229Z JUL 1945",
        "Atmospheric Visibility [km]": 50
    },
    "Threat Weapon Data":{
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        "Fission Fraction": 1,
        "Yield [kt]": 24.8,
        "HOB [m]": 30.48006,
        "HOB sigma [m]": 0,
        "CEP [m]": 0,
        "Neutron Leakage Spectrum":{
            "option":"H",
            "neutron yield [moles per kt]": 0.264,
            "energy bins [MeV]":[
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                3.00E-8, 4.00E-8, 5.00E-8, 7.00E-8, 1.00E-7, 1.25E-7, 1.50E-7, 1.84E-7,
                2.25E-7, 2.75E-7, 3.25E-7, 3.67E-7, 4.14E-7, 5.00E-7, 5.32E-7, 6.25E-7,
                6.83E-7, 8.00E-7, 8.67E-7, 1.00E-6, 1.04E-6, 1.08E-6, 1.13E-6, 1.30E-6,
                1.45E-6, 1.86E-6, 2.38E-6, 3.06E-6, 3.93E-6, 5.04E-6, 6.48E-6, 8.32E-6,
                1.07E-5, 1.37E-5, 1.76E-5, 2.26E-5, 2.90E-5, 3.73E-5, 4.79E-5, 6.14E-5,
                7.89E-5, 1.01E-4, 1.30E-4, 1.67E-4, 2.14E-4, 2.75E-4, 3.54E-4, 4.54E-4,
                5.83E-4, 7.49E-4, 9.61E-4, 1.23E-3, 1.58E-3, 2.03E-3, 2.25E-3, 2.49E-3,
                2.61E-3, 2.75E-3, 3.04E-3, 3.35E-3, 3.71E-3, 4.31E-3, 5.53E-3, 7.10E-3,
                9.12E-3, 1.06E-2, 1.17E-2, 1.50E-2, 1.93E-2, 2.19E-2, 2.36E-2, 2.42E-2,
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                5.25E-2, 5.66E-2, 6.74E-2, 7.20E-2, 7.95E-2, 8.25E-2, 8.65E-2, 9.80E-2,
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                2.47E-1, 2.73E-1, 2.87E-1, 2.95E-1, 2.97E-1, 2.98E-1, 3.02E-1, 3.34E-1,
                3.69E-1, 3.88E-1, 4.08E-1, 4.50E-1, 4.98E-1, 5.23E-1, 5.50E-1, 5.78E-1,
                6.08E-1, 6.39E-1, 6.72E-1, 7.07E-1, 7.43E-1, 7.81E-1, 8.21E-1, 8.63E-1,
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                2.59, 2.73, 2.87, 3.01, 3.17, 3.33, 3.68, 4.07, 4.49, 4.72, 4.97, 5.23,
                5.49, 5.77, 6.07, 6.38, 6.59, 6.70, 7.05, 7.41, 7.79, 8.19, 8.61, 9.05,
                9.51, 10.0, 10.5, 11.1, 11.6, 12.2, 12.5, 12.8, 13.5, 13.8, 14.2, 14.6,
                14.9, 15.7, 16.5, 16.9, 17.3, 20.0
            ],
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                1.40E-2, 1.08E-2, 8.59E-3, 6.76E-3, 5.36E-3, 5.23E-3, 4.57E-3, 4.19E-3, 4.43E-3,
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            "reference":"LA-UR-13-26113, Table 6"
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        "Photon Leakage Spectrum":{
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            "energy bins [MeV]":[
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                0.200, 0.300, 0.400, 0.450, 0.510, 0.512, 0.600, 0.700, 0.800, 1.000, 1.330,
                1.340, 1.500, 1.660, 2.000, 2.500, 3.000, 3.500, 4.000, 4.500, 5.000, 5.500,
                6.000, 6.500, 7.000, 7.500, 8.000, 10.000, 12.000, 14.000, 20.000, 30.000
            ],
            "probability [mol/MeV-kt]":[
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                5.85E-2, 8.00E-2, 7.46E-2, 7.76E-2, 5.83E-2, 5.48E-2, 6.76E-2, 3.85E-1, 7.32E-2,
                4.00E-2, 3.35E-2, 3.08E-2, 2.34E-2, 1.90E-2, 2.07E-2, 1.84E-2, 1.66E-2, 1.59E-2,
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                1.20E-4, 9.42E-4, 2.79E-5, 9.69E-6, 3.38E-8, 1.67E-13, 0
            ],
            "reference":"LA-UR-13-26113, Table 7"
        }
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            "Elevation (MSL) [m]": 1501,
                "R95 [km]": 0,
                "Depth [m]":0,
            "Heading [grid deg]": 0
            }
  },

        "System 1":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63233 27335",
            "Elevation (MSL) [m]": 1501,
                "R95 [km]": 0,
                "Depth [m]":0,
            "Heading [grid deg]": 0
            }
        },
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114         "System 2":{
115           "GIS Data":{
116             "Location (MGRS)": "13S CT 63233 27353",
117             "Elevation (MSL) [m]":1501,
118                 "R95 [km]": 0,
119                 "Depth [m]":0,
120             "Heading [grid deg]": 90
121             }
122
123         },
124         "System 5.1":{
125           "GIS Data":{
126             "Location (MGRS)": "13S CT 62395 28185",
127             "Elevation (MSL) [m]": 1488,
128                 "R95 [km]": 0,
129                 "Depth [m]":0,
130             "Heading [grid deg]": 314
131             }
132
133         },
134         "System 5.2":{
135           "GIS Data":{
136             "Location (MGRS)": "13S CT 63917 28331",
137             "Elevation (MSL) [m]": 1521,
138                 "R95 [km]": 0,
139                 "Depth [m]":0,
140             "Heading [grid deg]": 34
141             }
142
143         }
144     },
145
146   "Developer Name":"R. Boone Gilbreath",
147     "Developer Title":"Major, U.S. Army",
148     "Developer Organization":"Radiation Transport Applications Group, Los Alamos National Laboratory",
149
150   "Maintainer":"R. Boone Gilbreath",
151     "Maintainer Title":"Major, U.S. Army",
152     "Maintainer Organization":"Radiation Transport Applications Group, Los Alamos National Laboratory"
153 }
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E.2.3.3 System Data Files

E.2.3.3.1 Degraded SDFs

Listing E.20: The SYS_1 system data file for the Degraded system of systems (Degraded_SYS_1.sdf.json)

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  "HEADER COMMENTS":"SDF for System 1 of the Demonstration SOS",
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        "System 1":{
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        "type":"equipment",
            "color": "#0070C1",

        "VNTK": "30I1",

        "thresholds":{
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          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Subsystem A1":{

      "ID":"A_1",

      "type":"equipment",

          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      }
        },

        "Subsystem B1":{

```

```
      "ID":"B_1",

      "type":"equipment",

          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "Soldier 1":{
          "ID":"SM_1",
              "type":"human",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Soldier 2":{
          "ID":"SM_2",
              "type":"human",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Soldier 3":{
          "ID":"SM_3",
              "type":"human",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
```

```
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Generator Control Panel":{
          "ID":"GEN_CTRL",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
                }
            },

        "Subsystem D1":{

      "ID":"D_1",
          "type":"equipment",
          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "RWCIU 1":{
          "ID":"RWCIU_1",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
```

```
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Data Cable 1":{
          "ID":"DATA_CABLE_1",
          "VNTK": "null",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
                }
            },

        "Subsystem E1":{

      "ID":"E_1",
          "type":"equipment",
          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "Weapon Control Computer":{
          "ID":"WCC",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
```

```
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "VHF Antenna 1":{
          "ID":"VHF_1",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": 10,
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": 1E6,
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Fiber Optic Modem 1":{
          "ID":"FOM_1",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Fiber Optic Cable 1.1":{
          "ID":"FOC_1_1",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
                },
                "Fiber Optic Cable 1.2":{
          "ID":"FOC_1_2",
              "type":"equipment",
              "relative position":[0,0,0],
```

```
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": 1001,
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": 50,
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
                }
            }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "R/T Short-Range Communications w/ System 3":[
            {"R/T Data via Cable and Control Panel":{
        "Begin Node":["X_1"],
        "End Node":["BB_1"],
        "Has Path":[true],
        "Comment":"R/T data with System 3 via cable or control panel manual operation"
          }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1"],
        "End Node":["BB_1"],
        "Has Path":[false],
        "Comment":"Cannot R/T short-range data communications"
                }
            },
      {"R/T Data via Control Panel 3 ONLY":{
        "Begin Node":["X_1"],
        "End Node":["BB_1_1"],
        "Has Path":[true],
        "Comment":"R/T data only via control panel manual operation"
                }
            }
        ],
        "R/T Communications w/ System 5.1":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_2a", "EE_1_1"],
        "Has Path":[true, true],
        "Comment":"Communicate via VHF Radio and Fiber Optic Cable"
                }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_1", "EE_1_2a"],
        "Has Path":[false, false],
        "Comment":"Cannot communicate w/ System 5.1"
                }
```

```
            },
            {"Communicate via VHF Radio ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_2a"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
                }
            },
            {"Communicate via Fiber Optic Cable ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_1"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
                }
            }
        ],
        "R/T Communications w/ System 5.2":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_1", "EE_1_2b"],
        "Has Path":[true, true],
        "Comment":"Communicate via VHF Radio and Fiber Optic Cable"
                }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_1", "EE_1_2b"],
        "Has Path":[false, false],
        "Comment":"Cannot communicate w/ System 5.2"
                }
            },
            {"Communicate via VHF Radio ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_2b"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
        }
            },
            {"Communicate via Fiber Optic Cable ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_1"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
        }
            }
        ],
        "R/T Short-Range Communications w/ System 2":[
            {"R/T Data via Cable":{
        "Begin Node":["X_1"],
        "End Node":["DD_1"],
        "Has Path":[true],
        "Comment":"R/T data with System 1 via cable or control panel manual operation"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1"],
        "End Node":["DD_1"],
```

```
        "Has Path":[false],
        "Comment":"Cannot R/T short-range data communications"
        }
            }
        ]
  },

  "Structure":{
    "Admin Nodes":["AA_1", "BB_1_1", "BB_1", "DD_1", "EE_1_2a", "EE_1_2b", "EE_1_1", "EE_1_2", "EE_1"],
        "Terminal Nodes":["X_1","XX_1"],
    "Edges":{
            "X_1":["System 1"],
            "System 1":["Subsystem A1"],
            "Subsystem A1":["AA_1"],
            "AA_1":["Subsystem B1", "Subsystem D1"],
            "Subsystem B1":["Soldier 1", "Soldier 2", "Soldier 3"],
            "Soldier 1":["BB_1_1"],
            "Soldier 2":["BB_1_1"],
            "Soldier 3":["BB_1_1"],
            "BB_1_1":["Generator Control Panel", "Subsystem E1"],
            "Generator Control Panel":["BB_1"],
            "BB_1":["XX_1"],
            "Subsystem D1":["RWCIU 1"],
            "RWCIU 1":["Data Cable 1"],
            "Weapon Control Computer":["VHF Antenna 1", "Fiber Optic Modem 1"],
            "Data Cable 1":["DD_1"],
            "DD_1":["XX_1"],
            "Subsystem E1":["Weapon Control Computer"],
            "VHF Antenna 1":["EE_1_1"],
            "Fiber Optic Modem 1":["Fiber Optic Cable 1.1", "Fiber Optic Cable 1.2"],
            "Fiber Optic Cable 1.1":["EE_1_2a"],
            "Fiber Optic Cable 1.2":["EE_1_2b"],
            "EE_1_2a":["EE_1_2"],
            "EE_1_2b":["EE_1_2"],
            "EE_1_1":["EE_1"],
            "EE_1_2":["EE_1"],
            "EE_1":["XX_1"]
    }
  },

    "Developer Name":"R. Boone Gilbreath",
    "Developer Title":"Major, U.S. Army",
    "Developer Organization":"Radiation Transport Applications Group, Los Alamos National Laboratory",

  "Maintainer":"R. Boone Gilbreath",
    "Maintainer Title":"Major, U.S. Army",
    "Maintainer Organization":"Radiation Transport Applications Group, Los Alamos National Laboratory"
}
```

Listing E.21: The SYS_2 system data file for the Degraded system of systems (Degraded_SYS_2.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 2 of the Demonstration SOS",
  "System":{

        "System 2":{

        "ID": "System 2",

        "type":"equipment",
                  "color": "#E17800",

        "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Subsystem C2":{

      "ID":"C_2",
          "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                "RWCIU 2":{
                    "ID":"RWCIU_2",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
```

```
                "windspeed": 9,
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
            }
        }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "Communicates with System 1":[
            {"Communicates via Data Cable":{
        "Begin Node":["X_2"],
        "End Node":["DD_2"],
        "Has Path":[true],
        "Comment":"Communicates via data cable"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_2"],
        "End Node":["DD_2"],
        "Has Path":[false],
        "Comment":"Cannot communicate with System 1"
        }
            }
        ]
    },

  "Structure":{
    "Admin Nodes":["CC_2", "DD_2"],
        "Terminal Nodes":["X_2","XX_2"],
    "Edges":{
            "X_2":["System 2"],
            "System 2":["Subsystem C2"],
            "Subsystem C2":["CC_2"],
            "CC_2":["RWCIU 2"],
            "RWCIU 2":["DD_2"],
            "DD_2":["XX_2"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
     Laboratory",
  "Date":"1 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.22: The SYS_3 system data file for the Degraded system of systems (Degraded_SYS_3.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 3 of the Demonstration SOS",
  "System":{
        "System 3":{

        "ID": "System 3",

        "type":"equipment",
                  "color": "#EB0F1E",

              "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
            }
        }
  },

  "Subsystems":{

    "Subsystem A3":{

      "ID":"A_3",
          "type":"equipment",
          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                "J4_3":{
                    "ID":"J4_3",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
```

```
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
    }
      },

      "Subsystem B3":{

    "Subsystem ID":"B_3",
        "type":"equipment",
        "relative position":[0,0,0],

    "thresholds":{
      "static overpressure": "inf",
      "dynamic pressure": "inf",
      "windspeed": "inf",
      "thermal fluence": "inf",
      "total dose": "inf",
      "neutron dose": "inf",
      "neutron fluence": "inf",
      "gamma ray dose": "inf",
      "gamma ray dose rate": "inf",
      "PD": "inf"
    },
    "Components":{
                "Control Panel 3":{
                    "ID":"CTRL_3",
      "type":"equipment",
      "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                },
                "J5_3":{
                    "ID":"J5_3",
      "type":"equipment",
      "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
```

```
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
        }
            },

        "Subsystem C3":{

      "ID":"C_3",
          "type":"equipment",
          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                "J1_3":{
                    "ID":"J1_3",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                },
                "J2_3":{
                    "ID":"J2_3",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
```

```
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
        },
                "J3_3":{
                    "ID":"J3_3",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": 100,
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": 99.999,
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
            }
        }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "Powers External Loads":[
      {"Powers System 1 & System 2":{
        "Begin Node":["X_3", "X_3"],
        "End Node":["AA_3", "CC_3"],
        "Has Path":[true, true],
        "Comment":"Provides power to System 1 & System 2"
          }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_3"],
        "End Node":["AC_3"],
        "Has Path":[false],
        "Comment":"Cannot provide power to either system"
          }
            },
      {"Powers System 1 Only":{
        "Begin Node":["X_3"],
        "End Node":["CC_3"],
        "Has Path":[false],
        "Comment":"Provides power to System 1 only"
        }
            },
      {"Powers System 2 Only":{
        "Begin Node":["X_3"],
        "End Node":["AA_3"],
```

```
        "Has Path":[false],
        "Comment":"Provides power to System 2 only"
        }
      }
        ],

    "R/T Short-Range Communications w/ System 1":[
            {"R/T Data via Cable and Control Panel":{
        "Begin Node":["X_3"],
        "End Node":["BB_3"],
        "Has Path":[true],
        "Comment":"R/T data with System 1 via cable or control panel manual operation"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_3"],
        "End Node":["Control Panel 3"],
        "Has Path":[false],
        "Comment":"Cannot R/T short-range data communications"
        }
            },
            {"R/T Data via Control Panel 3 ONLY":{
                "Begin Node":["X_3"],
        "End Node":["BB_3_1"],
        "Has Path":[false],
        "Comment":"R/T data only via control panel manual operation"
                }
            }
        ]
  },

  "Structure":{
    "Admin Nodes":["AA_3", "BB_3", "BB_3_1", "CC_3", "AC_3"],
        "Terminal Nodes":["X_3","XX_3"],
    "Edges":{
            "X_3":["System 3"],
            "System 3":["Subsystem A3", "Subsystem B3", "Subsystem C3"],
            "Subsystem A3":["J4_3"],
            "J4_3":["AA_3"],
            "AA_3":["AC_3"],
            "Subsystem B3":["Control Panel 3"],
            "Control Panel 3":["BB_3_1"],
            "BB_3_1":["J5_3"],
            "J5_3":["BB_3"],
            "BB_3":["XX_3"],
            "Subsystem C3":["J1_3"],
            "J1_3":["J2_3"],
            "J2_3":["J3_3"],
            "J3_3":["CC_3"],
            "CC_3":["AC_3"],
            "AC_3":["XX_3"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
     Laboratory",
  "Date":"2 NOV 22",
```

```
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.23: The SYS_5_1 system data file for the Degraded system of systems (Degraded_SYS_5_1.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 5.1 of the Demonstration SOS",
  "System":{

        "System 5.1":{

        "ID": "System 5.1",

        "type":"equipment",
                  "color": "#00AA64",

        "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Shelter 5.1":{

      "ID":"SHELTER_5_1",
          "type":"equipment",
          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                "Fiber Optic Modem 5.1":{
                   "ID":"FOM_5_1",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
```

```
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                },
                "VHF Antenna 5.1":{
                    "ID":"VHF_5_1",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
            }
        }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "R/T Communications w/ System 1":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
        "Begin Node":["X_5_1", "X_5_1"],
        "End Node":["EE_5_1_2", "EE_5_1_1"],
        "Has Path":[true, true],
        "Comment":"Communicates w/ System 1 via VHF Radio and Fiber Optic Cable"
                }
      },
            {"NOT POSSIBLE":{
        "Begin Node":["X_5_1"],
        "End Node":["EE_5_1"],
        "Has Path":[false],
        "Comment":"Cannot communicate w/ System 1"
                }
      },
      {"Communicate via VHF Radio ONLY":{
        "Begin Node":["X_5_1"],
        "End Node":["EE_5_1_1"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
                }
```

```
      },
      {"Communicate via Fiber Optic Cable ONLY":{
        "Begin Node":["X_5_1"],
        "End Node":["EE_5_1_2"],
        "Has Path":[false],
        "Comment":"Communicate via Fiber Optic Cable ONLY"
          }
      }
    ]
  },

  "Structure":{
    "Admin Nodes":["EE_5_1", "EE_5_1_1", "EE_5_1_2"],
        "Terminal Nodes":["X_5_1","XX_5_1"],
    "Edges":{
           "X_5_1":["System 5.1"],
           "System 5.1":["Shelter 5.1"],
           "Shelter 5.1":["Fiber Optic Modem 5.1", "VHF Antenna 5.1"],
           "Fiber Optic Modem 5.1":["EE_5_1_2"],
           "VHF Antenna 5.1":["EE_5_1_1"],
           "EE_5_1_1":["EE_5_1"],
           "EE_5_1_2":["EE_5_1"],
           "EE_5_1":["XX_5_1"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
      Laboratory",
  "Date":"1 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.24: The SYS_5_2 system data file for the Degraded system of systems (Degraded_SYS_5_2.sdf.json)

```
{
    "HEADER COMMENTS":"SDF for System 5.2 of the Demonstration SOS",
    "System":{

        "System 5.2":{

            "ID": "System 5.2",

            "type":"equipment",
            "color": "#00AA64",

            "VNTK": "10Q3",

            "thresholds":{
                "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            }
        }
    },

    "Subsystems":{

        "Shelter 5.2":{

            "ID":"SHELTER_5_2",
                "type":"equipment",
                "relative position":[0,0,0],

            "thresholds":{
                "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            },
            "Components":{
                "Fiber Optic Modem 5.2":{
                    "ID":"FOM_5_2",
            "type":"equipment",
            "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
```

```
                        "dynamic pressure": "inf",
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "VHF Antenna 5.2":{
                    "ID":"VHF_5_2",
            "type":"equipment",
            "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                        "dynamic pressure": "inf",
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                }
            }
        }
    },

    "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

    "capabilities":{
        "R/T Communications w/ System 1":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
                "Begin Node":["X_5_2", "X_5_2"],
                "End Node":["EE_5_2_2", "EE_5_2_1"],
                "Has Path":[true, true],
                "Comment":"Communicates w/ System 1 via VHF Radio and Fiber Optic Cable"
                }
            },
            {"NOT POSSIBLE":{
                "Begin Node":["X_5_2"],
                "End Node":["EE_5_2"],
                "Has Path":[false],
                "Comment":"Cannot communicate w/ System 1"
                }
            },
            {"Communicate via VHF Radio ONLY":{
                "Begin Node":["X_5_2"],
                "End Node":["EE_5_2_1"],
                "Has Path":[false],
                "Comment":"Communicate via VHF Radio ONLY"
                }
```

```
            },
            {"Communicate via Fiber Optic Cable ONLY":{
                "Begin Node":["X_5_2"],
                "End Node":["EE_5_2_2"],
                "Has Path":[false],
                "Comment":"Communicate via Fiber Optic Cable ONLY"
                }
            }
        ]
    },

    "Structure":{
        "Admin Nodes":["EE_5_2", "EE_5_2_1", "EE_5_2_2"],
        "Terminal Nodes":["X_5_2","XX_5_2"],
        "Edges":{
           "X_5_2":["System 5.2"],
           "System 5.2":["Shelter 5.2"],
           "Shelter 5.2":["Fiber Optic Modem 5.2", "VHF Antenna 5.2"],
           "Fiber Optic Modem 5.2":["EE_5_2_2"],
           "VHF Antenna 5.2":["EE_5_2_1"],
           "EE_5_2_1":["EE_5_2"],
           "EE_5_2_2":["EE_5_2"],
           "EE_5_2":["XX_5_2"]
        }
    },

    "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos
     National Laboratory",
    "Date":"1 NOV 22",
    "Maintainer":"R. Boone Gilbreath"
}
```

E.2.3.3.2 Demo SDFs

Listing E.25: The SYS_1 system data file for the Demo system of systems (Demo_SYS_1.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 1 of the Demonstration SOS",
  "System":{
        "System 1":{
        "ID": "System 1",

        "VNTK": "null",

        "type":"equipment",
                    "color": "#0070C1",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Subsystem A1":{

      "ID":"A_1",

      "type":"equipment",

      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      }
        },

        "Subsystem B1":{

      "ID":"B_1",

```

```
      "type":"equipment",

      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "Soldier 1":{
          "ID":"SM_1",
          "type":"human",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Soldier 2":{
          "ID":"SM_2",
          "type":"human",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Soldier 3":{
          "ID":"SM_3",
          "type":"human",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
```

```
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Generator Control Panel":{
          "ID":"GEN_CTRL",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
                }
            },

        "Subsystem D1":{

      "ID":"D_1",
      "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "RWCIU 1":{
          "ID":"RWCIU_1",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
```

```
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Data Cable 1":{
          "ID":"DATA_CABLE_1",
          "VNTK": "null",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
                }
            },

        "Subsystem E1":{

      "ID":"E_1",
      "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "Weapon Control Computer":{
          "ID":"WCC",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
```

```
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "VHF Antenna 1":{
          "ID":"VHF_1",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Fiber Optic Modem 1":{
          "ID":"FOM_1",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Fiber Optic Cable 1.1":{
          "ID":"FOC_1_1",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
                },
                "Fiber Optic Cable 1.2":{
          "ID":"FOC_1_2",
          "type":"equipment",
          "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
```

```
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
                }
            }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "R/T Short-Range Communications w/ System 3":[
            {"R/T Data via Cable and Control Panel":{
        "Begin Node":["X_1"],
        "End Node":["BB_1"],
        "Has Path":[true],
        "Comment":"R/T data with System 3 via cable or control panel manual operation"
          }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1"],
        "End Node":["BB_1"],
        "Has Path":[false],
        "Comment":"Cannot R/T short-range data communications"
                }
            },
      {"R/T Data via Control Panel 3 ONLY":{
        "Begin Node":["X_1"],
        "End Node":["BB_1_1"],
        "Has Path":[true],
        "Comment":"R/T data only via control panel manual operation"
                }
            }
        ],
        "R/T Communications w/ System 5.1":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_2a", "EE_1_1"],
        "Has Path":[true, true],
        "Comment":"Communicate via VHF Radio and Fiber Optic Cable"
                }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_1", "EE_1_2a"],
        "Has Path":[false, false],
        "Comment":"Cannot communicate w/ System 5.1"
                }
            },
            {"Communicate via VHF Radio ONLY":{
```

```
        "Begin Node":["X_1"],
        "End Node":["EE_1_2a"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
                }
            },
            {"Communicate via Fiber Optic Cable ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_1"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
                }
            }
        ],
        "R/T Communications w/ System 5.2":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_1", "EE_1_2b"],
        "Has Path":[true, true],
        "Comment":"Communicate via VHF Radio and Fiber Optic Cable"
                }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_1", "EE_1_2b"],
        "Has Path":[false, false],
        "Comment":"Cannot communicate w/ System 5.2"
                }
            },
            {"Communicate via VHF Radio ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_2b"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
        }
            },
            {"Communicate via Fiber Optic Cable ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_1"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
        }
            }
        ],
        "R/T Short-Range Communications w/ System 2":[
            {"R/T Data via Cable":{
        "Begin Node":["X_1"],
        "End Node":["DD_1"],
        "Has Path":[true],
        "Comment":"R/T data with System 1 via cable or control panel manual operation"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1"],
        "End Node":["DD_1"],
        "Has Path":[false],
        "Comment":"Cannot R/T short-range data communications"
```

```
        }
            }
        ]
  },

  "Structure":{
    "Admin Nodes":["AA_1", "BB_1_1", "BB_1", "DD_1", "EE_1_2a", "EE_1_2b", "EE_1_1", "EE_1_2", "EE_1"],
        "Terminal Nodes":["X_1","XX_1"],
    "Edges":{
            "X_1":["System 1"],
            "System 1":["Subsystem A1"],
            "Subsystem A1":["AA_1"],
            "AA_1":["Subsystem B1", "Subsystem D1"],
            "Subsystem B1":["Soldier 1", "Soldier 2", "Soldier 3"],
            "Soldier 1":["BB_1_1"],
            "Soldier 2":["BB_1_1"],
            "Soldier 3":["BB_1_1"],
            "BB_1_1":["Generator Control Panel", "Subsystem E1"],
            "Generator Control Panel":["BB_1"],
            "BB_1":["XX_1"],
            "Subsystem D1":["RWCIU 1"],
            "RWCIU 1":["Data Cable 1"],
            "Weapon Control Computer":["VHF Antenna 1", "Fiber Optic Modem 1"],
            "Data Cable 1":["DD_1"],
            "DD_1":["XX_1"],
            "Subsystem E1":["Weapon Control Computer"],
            "VHF Antenna 1":["EE_1_1"],
            "Fiber Optic Modem 1":["Fiber Optic Cable 1.1", "Fiber Optic Cable 1.2"],
            "Fiber Optic Cable 1.1":["EE_1_2a"],
            "Fiber Optic Cable 1.2":["EE_1_2b"],
            "EE_1_2a":["EE_1_2"],
            "EE_1_2b":["EE_1_2"],
            "EE_1_1":["EE_1"],
            "EE_1_2":["EE_1"],
            "EE_1":["XX_1"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
     Laboratory",
  "Date":"1 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.26: The SYS_2 system data file for the Demo system of systems (Demo_SYS_2.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 2 of the Demonstration SOS",
  "System":{

        "System 2":{

        "ID": "System 2",

        "type":"equipment",
                    "color": "#E17800",

        "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Subsystem C2":{

      "ID":"C_2",

      "type":"equipment",

      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                    "RWCIU 2":{
                          "ID":"RWCIU_2",
          "type":"equipment",
          "relative position":[0,0,0],
                          "thresholds":{
```

```
                                "static overpressure": "inf",
                    "dynamic pressure": "inf",
                    "windspeed": 9,
                    "thermal fluence": "inf",
                    "total dose": "inf",
                    "neutron dose": "inf",
                    "neutron fluence": "inf",
                    "gamma ray dose": "inf",
                    "gamma ray dose rate": "inf",
                    "PD": "inf"
                      }
                  }
              }
          }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "Communicates with System 1":[
            {"Communicates via Data Cable":{
        "Begin Node":["X_2"],
        "End Node":["DD_2"],
        "Has Path":[true],
        "Comment":"Communicates via data cable"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_2"],
        "End Node":["DD_2"],
        "Has Path":[false],
        "Comment":"Cannot communicate with System 1"
        }
            }
        ]
    },

  "Structure":{
    "Admin Nodes":["CC_2", "DD_2"],
        "Terminal Nodes":["X_2","XX_2"],
    "Edges":{
            "X_2":["System 2"],
            "System 2":["Subsystem C2"],
            "Subsystem C2":["CC_2"],
            "CC_2":["RWCIU 2"],
            "RWCIU 2":["DD_2"],
            "DD_2":["XX_2"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
     Laboratory",
  "Date":"1 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.27: The SYS_3 system data file for the Demo system of systems (Demo_SYS_3.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 3 of the Demonstration SOS",
  "System":{
          "System 3":{

      "ID": "System 3",

      "type":"equipment",
                          "color": "#EB0F1E",

      "VNTK": "null",

          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"
            }
    }
  },

  "Subsystems":{

    "Subsystem A3":{

      "ID":"A_3",

      "type":"equipment",

      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                "J4_3":{
                    "ID":"J4_3",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
```

```
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
    }
      },

      "Subsystem B3":{

    "ID":"B_3",
        "type":"equipment",
        "relative position":[0,0,0],

    "thresholds":{
      "static overpressure": "inf",
      "dynamic pressure": "inf",
      "windspeed": "inf",
      "thermal fluence": "inf",
      "total dose": "inf",
      "neutron dose": "inf",
      "neutron fluence": "inf",
      "gamma ray dose": "inf",
      "gamma ray dose rate": "inf",
      "PD": "inf"
    },
    "Components":{
                "Control Panel 3":{
                    "ID":"CTRL_3",
      "type":"equipment",
      "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                },
                "J5_3":{
                    "ID":"J5_3",
      "type":"equipment",
      "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
```

```
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
      }
          },

      "Subsystem C3":{

    "Subsystem ID":"C_3",
        "type":"equipment",
        "relative position":[0,0,0],

    "thresholds":{
      "static overpressure": "inf",
      "dynamic pressure": "inf",
      "windspeed": "inf",
      "thermal fluence": "inf",
      "total dose": "inf",
      "neutron dose": "inf",
      "neutron fluence": "inf",
      "gamma ray dose": "inf",
      "gamma ray dose rate": "inf",
      "PD": "inf"
    },
    "Components":{
                "J1_3":{
                    "ID":"J1_3",
      "type":"equipment",
      "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                },
                "J2_3":{
                    "ID":"J2_3",
      "type":"equipment",
      "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
```

```
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
        },
                "J3_3":{
                    "ID":"J3_3",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
            }
        }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "Powers External Loads":[
      {"Powers System 1 & System 2":{
        "Begin Node":["X_3", "X_3"],
        "End Node":["AA_3", "CC_3"],
        "Has Path":[true, true],
        "Comment":"Provides power to System 1 & System 2"
          }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_3"],
        "End Node":["AC_3"],
        "Has Path":[false],
        "Comment":"Cannot provide power to either system"
          }
            },
      {"Powers System 1 Only":{
        "Begin Node":["X_3"],
        "End Node":["CC_3"],
        "Has Path":[false],
        "Comment":"Provides power to System 1 only"
        }
            },
      {"Powers System 2 Only":{
```

```
        "Begin Node":["X_3"],
        "End Node":["AA_3"],
        "Has Path":[false],
        "Comment":"Provides power to System 2 only"
        }
      }
        ],

    "R/T Short-Range Communications w/ System 1":[
            {"R/T Data via Cable and Control Panel":{
        "Begin Node":["X_3"],
        "End Node":["BB_3"],
        "Has Path":[true],
        "Comment":"R/T data with System 1 via cable or control panel manual operation"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_3"],
        "End Node":["Control Panel 3"],
        "Has Path":[false],
        "Comment":"Cannot R/T short-range data communications"
        }
            },
            {"R/T Data via Control Panel 3 ONLY":{
                "Begin Node":["X_3"],
        "End Node":["BB_3_1"],
        "Has Path":[false],
        "Comment":"R/T data only via control panel manual operation"
                }
            }
        ]
  },

  "Structure":{
    "Admin Nodes":["AA_3", "BB_3", "BB_3_1", "CC_3", "AC_3"],
        "Terminal Nodes":["X_3","XX_3"],
    "Edges":{
            "X_3":["System 3"],
            "System 3":["Subsystem A3", "Subsystem B3", "Subsystem C3"],
            "Subsystem A3":["J4_3"],
            "J4_3":["AA_3"],
            "AA_3":["AC_3"],
            "Subsystem B3":["Control Panel 3"],
            "Control Panel 3":["BB_3_1"],
            "BB_3_1":["J5_3"],
            "J5_3":["BB_3"],
            "BB_3":["XX_3"],
            "Subsystem C3":["J1_3"],
            "J1_3":["J2_3"],
            "J2_3":["J3_3"],
            "J3_3":["CC_3"],
            "CC_3":["AC_3"],
            "AC_3":["XX_3"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
```

```
      Laboratory",
  "Date":"2 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.28: The SYS_5_1 system data file for the Demo scenario (Demo_SYS_5_1.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 5.1 of the Demonstration SOS",
  "System":{

        "System 5.1":{

        "ID": "System 5.1",

        "type":"equipment",
                  "color": "#00AA64",

        "VNTK": "10Q5",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Shelter 5.1":{

      "ID":"SHELTER_5_1",

      "type":"equipment",

      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                "Fiber Optic Modem 5.1":{
                   "ID":"FOM_5_1",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
```

```
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                },
                "VHF Antenna 5.1":{
                    "ID":"VHF_5_1",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
            }
        }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "R/T Communications w/ System 1":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
        "Begin Node":["X_5_1", "X_5_1"],
        "End Node":["EE_5_1_2", "EE_5_1_1"],
        "Has Path":[true, true],
        "Comment":"Communicates w/ System 1 via VHF Radio and Fiber Optic Cable"
                }
      },
            {"NOT POSSIBLE":{
        "Begin Node":["X_5_1"],
        "End Node":["EE_5_1"],
        "Has Path":[false],
        "Comment":"Cannot communicate w/ System 1"
                }
      },
      {"Communicate via VHF Radio ONLY":{
        "Begin Node":["X_5_1"],
        "End Node":["EE_5_1_1"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
```

```
                }
      },
      {"Communicate via Fiber Optic Cable ONLY":{
        "Begin Node":["X_5_1"],
        "End Node":["EE_5_1_2"],
        "Has Path":[false],
        "Comment":"Communicate via Fiber Optic Cable ONLY"
          }
      }
    ]
  },

  "Structure":{
    "Admin Nodes":["EE_5_1", "EE_5_1_1", "EE_5_1_2"],
        "Terminal Nodes":["X_5_1","XX_5_1"],
    "Edges":{
           "X_5_1":["System 5.1"],
           "System 5.1":["Shelter 5.1"],
           "Shelter 5.1":["Fiber Optic Modem 5.1", "VHF Antenna 5.1"],
           "Fiber Optic Modem 5.1":["EE_5_1_2"],
           "VHF Antenna 5.1":["EE_5_1_1"],
           "EE_5_1_1":["EE_5_1"],
           "EE_5_1_2":["EE_5_1"],
           "EE_5_1":["XX_5_1"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
      Laboratory",
  "Date":"1 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.29: The SYS_5_2 system data file for the Demo system of systems (Demo_SYS_5_2.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 5.2 of the Demonstration SOS",
  "System":{

        "System 5.2":{

        "ID": "System 5.2",
        "type":"equipment",
        "VNTK": "null",
                    "color": "#00AA64",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Shelter 5.2":{

      "ID":"SHELTER_5_2",
          "type":"equipment",
          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                "Fiber Optic Modem 5.2":{
                    "ID":"FOM_5_2",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
```

```
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                },
                "VHF Antenna 5.2":{
                    "ID":"VHF_5_2",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
            }
        }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "R/T Communications w/ System 1":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
        "Begin Node":["X_5_2", "X_5_2"],
        "End Node":["EE_5_2_2", "EE_5_2_1"],
        "Has Path":[true, true],
        "Comment":"Communicates w/ System 1 via VHF Radio and Fiber Optic Cable"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_5_2"],
        "End Node":["EE_5_2"],
        "Has Path":[false],
        "Comment":"Cannot communicate w/ System 1"
        }
            },
      {"Communicate via VHF Radio ONLY":{
        "Begin Node":["X_5_2"],
        "End Node":["EE_5_2_1"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
        }
            },
      {"Communicate via Fiber Optic Cable ONLY":{
        "Begin Node":["X_5_2"],
```

```
        "End Node":["EE_5_2_2"],
        "Has Path":[false],
        "Comment":"Communicate via Fiber Optic Cable ONLY"
        }
      }
    ]
  },

  "Structure":{
    "Admin Nodes":["EE_5_2", "EE_5_2_1", "EE_5_2_2"],
        "Terminal Nodes":["X_5_2","XX_5_2"],
    "Edges":{
          "X_5_2":["System 5.2"],
          "System 5.2":["Shelter 5.2"],
          "Shelter 5.2":["Fiber Optic Modem 5.2", "VHF Antenna 5.2"],
          "Fiber Optic Modem 5.2":["EE_5_2_2"],
          "VHF Antenna 5.2":["EE_5_2_1"],
          "EE_5_2_1":["EE_5_2"],
          "EE_5_2_2":["EE_5_2"],
          "EE_5_2":["XX_5_2"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
     Laboratory",
  "Date":"1 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

E.2.3.3.3 Errors SDFs

Listing E.30: The SYS_1 system data file for the Errors system of systems (Errors_SYS_1.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 1 of the Demonstration SOS",
  "System":{
        "System 1":{
        "ID": "System 1",

        "type":"equipment",
                    "color": "#0070C1",

        "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Subsystem A1":{

      "ID":"A_1",
          "type":"equipment",
          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      }
        },

        "Subsystem B1":{

      "ID":"B_1",
          "type":"equipment",
          "relative position":[0,0,0],

```

```
    "thresholds":{
      "static overpressure": "inf",
      "dynamic pressure": "inf",
      "windspeed": "inf",
      "thermal fluence": "inf",
      "total dose": "inf",
      "neutron dose": "inf",
      "neutron fluence": "inf",
      "gamma ray dose": "inf",
      "gamma ray dose rate": "inf",
      "PD": "inf"
    },
    "Components":{
      "Soldier 1":{
        "ID":"SM_1",
            "type":"human",
            "relative position":[0,0,0],
        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": 1,
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"}
      },
              "Soldier 2":{
        "ID":"SM_2",
            "type":"human",
            "relative position":[0,0,0],
        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": 1,
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"}
      },
              "Soldier 3":{
        "ID":"SM_3",
            "type":"human",
            "relative position":[0,0,0],
        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": 1,
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
```

```
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Generator Control Panel":{
          "ID":"GEN_CTRL",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
                }
            },

        "Subsystem D1":{

      "ID":"D_1",
          "type":"equipment",
          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "RWCIU 1":{
          "ID":"RWCIU_1",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
```

```
        },
                "Data Cable 1":{
          "ID":"DATA_CABLE_1",
              "type":"equipment",
              "relative position":[0,0,0],
          "VNTK": "null",
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
                }
            },

        "Subsystem E1":{

      "ID":"E_1",
          "type":"equipment",
          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
        "Weapon Control Computer":{
          "ID":"WCC",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": "inf",
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "VHF Antenna 1":{
```

```
          "ID":"VHF_1",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": 1E6,
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Fiber Optic Modem 1":{
          "ID":"FOM_1",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Fiber Optic Cable 1.1":{
          "ID":"FOC_1_1",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
                },
                "Fiber Optic Cable 1.2":{
          "ID":"FOC_1_2",
              "type":"equipment",
              "relative position":[0,0,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
```

```
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": 50,
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
                }
            }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "R/T Short-Range Communications w/ System 3":[
            {"R/T Data via Cable and Control Panel":{
        "Begin Node":["X_1"],
        "End Node":["BB_1"],
        "Has Path":[true],
        "Comment":"R/T data with System 3 via cable or control panel manual operation"
          }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1"],
        "End Node":["BB_1"],
        "Has Path":[false],
        "Comment":"Cannot R/T short-range data communications"
                }
            },
      {"R/T Data via Control Panel 3 ONLY":{
        "Begin Node":["X_1"],
        "End Node":["BB_1_1"],
        "Has Path":[true],
        "Comment":"R/T data only via control panel manual operation"
                }
            }
        ],
        "R/T Communications w/ System 5.1":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_2a", "EE_1_1"],
        "Has Path":[true, true],
        "Comment":"Communicate via VHF Radio and Fiber Optic Cable"
                }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_1", "EE_1_2a"],
        "Has Path":[false, false],
        "Comment":"Cannot communicate w/ System 5.1"
                }
            },
            {"Communicate via VHF Radio ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_2a"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
```

```
                }
            },
            {"Communicate via Fiber Optic Cable ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_1"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
                }
            }
        ],
        "R/T Communications w/ System 5.2":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_1", "EE_1_2b"],
        "Has Path":[true, true],
        "Comment":"Communicate via VHF Radio and Fiber Optic Cable"
                }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1", "X_1"],
        "End Node":["EE_1_1", "EE_1_2b"],
        "Has Path":[false, false],
        "Comment":"Cannot communicate w/ System 5.2"
                }
            },
            {"Communicate via VHF Radio ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_2b"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
        }
            },
            {"Communicate via Fiber Optic Cable ONLY":{
        "Begin Node":["X_1"],
        "End Node":["EE_1_1"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
        }
            }
        ],
        "R/T Short-Range Communications w/ System 2":[
            {"R/T Data via Cable":{
        "Begin Node":["X_1"],
        "End Node":["DD_1"],
        "Has Path":[true],
        "Comment":"R/T data with System 1 via cable or control panel manual operation"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1"],
        "End Node":["DD_1"],
        "Has Path":[false],
        "Comment":"Cannot R/T short-range data communications"
        }
            }
        ]
    },
```

```
{
  "Structure":{
    "Admin Nodes":["AA_1", "BB_1_1", "BB_1", "DD_1", "EE_1_2a", "EE_1_2b", "EE_1_1", "EE_1_2", "EE_1"],
        "Terminal Nodes":["X_1","XX_1"],
    "Edges":{
            "X_1":["System 1"],
            "System 1":["Subsystem A1"],
            "Subsystem A1":["AA_1"],
            "AA_1":["Subsystem B1", "Subsystem D1"],
            "Subsystem B1":["Soldier 1", "Soldier 2", "Soldier 3"],
            "Soldier 1":["BB_1_1"],
            "Soldier 2":["BB_1_1"],
            "Soldier 3":["BB_1_1"],
            "BB_1_1":["Generator Control Panel", "Subsystem E1"],
            "Generator Control Panel":["BB_1"],
            "BB_1":["XX_1"],
            "Subsystem D1":["RWCIU 1"],
            "RWCIU 1":["Data Cable 1"],
            "Weapon Control Computer":["VHF Antenna 1", "Fiber Optic Modem 1"],
            "Data Cable 1":["DD_1"],
            "DD_1":["XX_1"],
            "Subsystem E1":["Weapon Control Computer"],
            "VHF Antenna 1":["EE_1_1"],
            "Fiber Optic Modem 1":["Fiber Optic Cable 1.1", "Fiber Optic Cable 1.2"],
            "Fiber Optic Cable 1.1":["EE_1_2a"],
            "Fiber Optic Cable 1.2":["EE_1_2b"],
            "EE_1_2a":["EE_1_2"],
            "EE_1_2b":["EE_1_2"],
            "EE_1_1":["EE_1"],
            "EE_1_2":["EE_1"],
            "EE_1":["XX_1"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
      Laboratory",
  "Date":"1 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.31: The SYS_2 system data file for the Errors system of systems (Errors_SYS_2.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 2 of the Demonstration SOS",
  "System":{

        "System 2":{

        "ID": "System 2",

        "type":"equipment",
                    "color": "#E17800",

        "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Subsystem C2":{

      "ID":"C_2",
          "type":"equipment",
          "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                "RWCIU 2":{
                    "ID":"RWCIU_2",
        "type":"equipment",
        "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
```

```
                "windspeed": 9,
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
            }
        }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "Communicates with System 1":[
            {"Communicates via Data Cable":{
        "Begin Node":["X_2"],
        "End Node":["DD_2"],
        "Has Path":[true],
        "Comment":"Communicates via data cable"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_2"],
        "End Node":["DD_2"],
        "Has Path":[false],
        "Comment":"Cannot communicate with System 1"
        }
            }
        ]
    },

  "Structure":{
    "Admin Nodes":["CC_2", "DD_2"],
        "Terminal Nodes":["X_2","XX_2"],
    "Edges":{
            "X_2":["System 2"],
            "System 2":["Subsystem C2"],
            "Subsystem C2":["CC_2"],
            "CC_2":["RWCIU 2"],
            "RWCIU 2":["DD_2"],
            "DD_2":["XX_2"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
     Laboratory",
  "Date":"1 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.32: The SYS_3 system data file for the Errors system of systems (Errors_SYS_3.sdf.json)


```
{
  "HEADER COMMENTS":"SDF for System 3 of the Demonstration SOS",
  "System":{
        "System 3":{

        "ID": "System 3",

        "type":"equipment",
                    "color": "#EB0F1E",

           "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": 1,
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
            }
    }
  },

  "Subsystems":{

    "Subsystem A3":{

      "ID":"A_3",

      "type":"equipment",

      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                "J4_3":{
                    "ID":"J4_3",
      "type":"equipment",
      "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
```

```
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
    }
      },

      "Subsystem B3":{

    "ID":"B_3",
    "type":"equipment",
    "relative position":[0,0,0],

    "thresholds":{
      "static overpressure": "inf",
      "dynamic pressure": "inf",
      "windspeed": "inf",
      "thermal fluence": "inf",
      "total dose": "inf",
      "neutron dose": "inf",
      "neutron fluence": "inf",
      "gamma ray dose": "inf",
      "gamma ray dose rate": "inf",
      "PD": "inf"
    },
    "Components":{
              "Control Panel 3":{
                  "ID":"CTRL_3",
    "type":"equipment",
    "relative position":[0,0,0],
                  "thresholds":{
                      "static overpressure": "inf",
              "dynamic pressure": "inf",
              "windspeed": "inf",
              "thermal fluence": "inf",
              "total dose": "inf",
              "neutron dose": "inf",
              "neutron fluence": "inf",
              "gamma ray dose": "inf",
              "gamma ray dose rate": "inf",
              "PD": "inf"
                  }
              },
              "J5_3":{
                  "ID":"J5_3",
    "type":"equipment",
    "relative position":[0,0,0],
                  "thresholds":{
                      "static overpressure": "inf",
              "dynamic pressure": "inf",
```

```
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
      }
          },

       "Subsystem C3":{

     "ID":"C_3",
     "type":"equipment",
     "relative position":[0,0,0],

     "thresholds":{
       "static overpressure": "inf",
       "dynamic pressure": "inf",
       "windspeed": "inf",
       "thermal fluence": "inf",
       "total dose": "inf",
       "neutron dose": "inf",
       "neutron fluence": "inf",
       "gamma ray dose": "inf",
       "gamma ray dose rate": "inf",
       "PD": "inf"
     },
     "Components":{
                "J1_3":{
                    "ID":"J1_3",
     "type":"equipment",
     "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                },
                "J2_3":{
                    "ID":"J2_3",
     "type":"equipment",
     "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
```

```
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
        },
                "J3_3":{
                    "ID":"J3_3",
      "type":"equipment",
      "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": 99.999,
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
            }
        }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "Powers External Loads":[
      {"Powers System 1 & System 2":{
        "Begin Node":["X_3", "X_3"],
        "End Node":["AA_3", "CC_3"],
        "Has Path":[true, true],
        "Comment":"Provides power to System 1 & System 2"
          }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_3"],
        "End Node":["AC_3"],
        "Has Path":[false],
        "Comment":"Cannot provide power to either system"
          }
            },
      {"Powers System 1 Only":{
        "Begin Node":["X_3"],
        "End Node":["CC_3"],
        "Has Path":[false],
        "Comment":"Provides power to System 1 only"
        }
            },
      {"Powers System 2 Only":{
```

```
        "Begin Node":["X_3"],
        "End Node":["AA_3"],
        "Has Path":[false],
        "Comment":"Provides power to System 2 only"
        }
      }
        ],

    "R/T Short-Range Communications w/ System 1":[
            {"R/T Data via Cable and Control Panel":{
        "Begin Node":["X_3"],
        "End Node":["BB_3"],
        "Has Path":[true],
        "Comment":"R/T data with System 1 via cable or control panel manual operation"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_3"],
        "End Node":["Control Panel 3"],
        "Has Path":[false],
        "Comment":"Cannot R/T short-range data communications"
        }
            },
            {"R/T Data via Control Panel 3 ONLY":{
                "Begin Node":["X_3"],
        "End Node":["BB_3_1"],
        "Has Path":[false],
        "Comment":"R/T data only via control panel manual operation"
                }
            }
        ]
  },

  "Structure":{
    "Admin Nodes":["AA_3", "BB_3", "BB_3_1", "CC_3", "AC_3"],
        "Terminal Nodes":["X_3","XX_3"],
    "Edges":{
            "X_3":["System 3"],
            "System 3":["Subsystem A3", "Subsystem B3", "Subsystem C3"],
            "Subsystem A3":["J4_3"],
            "J4_3":["AA_3"],
            "AA_3":["AC_3"],
            "Subsystem B3":["Control Panel 3"],
            "Control Panel 3":["BB_3_1"],
            "BB_3_1":["J5_3"],
            "J5_3":["BB_3"],
            "BB_3":["XX_3"],
            "Subsystem C3":["J1_3"],
            "J1_3":["J2_3"],
            "J2_3":["J3_3"],
            "J3_3":["CC_3"],
            "CC_3":["AC_3"],
            "AC_3":["XX_3"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
```

```
    Laboratory",
  "Date":"2 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.33: The SYS_5_1 system data file for the Errors system of systems (Errors_SYS_5_1.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 5.1 of the Demonstration SOS",
  "System":{

        "System 5.1":{

        "ID": "System 5.1",

        "type":"equipment",
                    "color": "#00AA64",

        "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Shelter 5.1":{

      "ID":"SHELTER_5_1",
      "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                "Fiber Optic Modem 5.1":{
                    "ID":"FOM_5_1",
      "type":"equipment",
      "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
```

```
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                },
                "VHF Antenna 5.1":{
                    "ID":"VHF_5_1",
     "type":"equipment",
     "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
            }
        }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "R/T Communications w/ System 1":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
        "Begin Node":["X_5_1", "X_5_1"],
        "End Node":["EE_5_1_2", "EE_5_1_1"],
        "Has Path":[true, true],
        "Comment":"Communicates w/ System 1 via VHF Radio and Fiber Optic Cable"
                }
     },
            {"NOT POSSIBLE":{
        "Begin Node":["X_5_1"],
        "End Node":["EE_5_1"],
        "Has Path":[false],
        "Comment":"Cannot communicate w/ System 1"
                }
     },
     {"Communicate via VHF Radio ONLY":{
        "Begin Node":["X_5_1"],
        "End Node":["EE_5_1_1"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
                }
     },
```

```
      {"Communicate via Fiber Optic Cable ONLY":{
        "Begin Node":["X_5_1"],
        "End Node":["EE_5_1_2"],
        "Has Path":[false],
        "Comment":"Communicate via Fiber Optic Cable ONLY"
          }
      }
    ]
  },

  "Structure":{
    "Admin Nodes":["EE_5_1", "EE_5_1_1", "EE_5_1_2"],
        "Terminal Nodes":["X_5_1","XX_5_1"],
    "Edges":{
           "X_5_1":["System 5.1"],
           "System 5.1":["Shelter 5.1"],
           "Shelter 5.1":["Fiber Optic Modem 5.1", "VHF Antenna 5.1"],
           "Fiber Optic Modem 5.1":["EE_5_1_2"],
           "VHF Antenna 5.1":["EE_5_1_1"],
           "EE_5_1_1":["EE_5_1"],
           "EE_5_1_2":["EE_5_1"],
           "EE_5_1":["XX_5_1"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
      Laboratory",
  "Date":"1 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.34: The SYS_5_2 system data file for the Errors system of systems (Errors_SYS_5_2.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 5.2 of the Demonstration SOS",
  "System":{

        "System 5.2":{

        "ID": "System 5.2",

        "type":"equipment",
                    "color": "#00AA64",

        "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Shelter 5.2":{

      "ID":"SHELTER_5_2",
      "type":"equipment",
      "relative position":[0,0,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                "Fiber Optic Modem 5.2":{
                    "ID":"FOM_5_2",
      "type":"equipment",
      "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
```

```
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                },
                "VHF Antenna 5.2":{
                    "ID":"VHF_5_2",
     "type":"equipment",
     "relative position":[0,0,0],
                    "thresholds":{
                        "static overpressure": "inf",
                "dynamic pressure": "inf",
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
                    }
                }
            }
        }
    },

  "functions":"NOTE: This is a placeholder for future work using subsystem and system functions
     underlying system capabilities.",

  "capabilities":{
    "R/T Communications w/ System 1":[
            {"Communicate via VHF Radio and Fiber Optic Cable":{
        "Begin Node":["X_5_2", "X_5_2"],
        "End Node":["EE_5_2_2", "EE_5_2_1"],
        "Has Path":[true, true],
        "Comment":"Communicates w/ System 1 via VHF Radio and Fiber Optic Cable"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_5_2"],
        "End Node":["EE_5_2"],
        "Has Path":[false],
        "Comment":"Cannot communicate w/ System 1"
        }
            },
     {"Communicate via VHF Radio ONLY":{
        "Begin Node":["X_5_2"],
        "End Node":["EE_5_2_1"],
        "Has Path":[false],
        "Comment":"Communicate via VHF Radio ONLY"
        }
            },
```

```
      {"Communicate via Fiber Optic Cable ONLY":{
        "Begin Node":["X_5_2"],
        "End Node":["EE_5_2_2"],
        "Has Path":[false],
        "Comment":"Communicate via Fiber Optic Cable ONLY"
        }
      }
    ]
  },

  "Structure":{
    "Admin Nodes":["EE_5_2", "EE_5_2_1", "EE_5_2_2"],
        "Terminal Nodes":["X_5_2","XX_5_2"],
    "Edges":{
           "X_5_2":["System 5.2"],
           "System 5.2":["Shelter 5.2"],
           "Shelter 5.2":["Fiber Optic Modem 5.2", "VHF Antenna 5.2"],
           "Fiber Optic Modem 5.2":["EE_5_2_2"],
           "VHF Antenna 5.2":["EE_5_2_1"],
           "EE_5_2_1":["EE_5_2"],
           "EE_5_2_2":["EE_5_2"],
           "EE_5_2":["XX_5_2"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
     Laboratory",
  "Date":"1 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

E.2.4 Weapon Environment Tools (EnvTools) Test Data

E.2.4.1 SOS Data Files

In addition to the file listing shown here, unit testing of the EnvTools package also employed the `Demo.sosdf.json` file used in the SOS package tests.

Listing E.35: The Tiny system-of-systems data file (Tiny.sosdf.json)

```
{
    "HEADER COMMENTS":"The following data defines the SOS for analysis.",
    "System of Systems":{
        "Tiny_SOS":{
            "ID":"Tiny_SOS"
        }
    },

    "Systems":{
        "System 1":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Tiny_SDFs/SYS_1.sdf.json
    "
        },
        "System 2":{
            "SDF Path":"C:/Users/339528/Documents/Git/NuSCAP/tests/sos/Demo_SOS/Tiny_SDFs/SYS_2.sdf.json
    "
        }
    },

    "SOS capabilities":{
        "Capability 1":[
            {"100% bin":{
        "Begin Node":["X", "X", "Generator Control Panel"],
        "End Node":["XX", "Soldier 1", "CC_2"],
        "Has Path":[true],
        "Comment":"Capability 1 exists"
        }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X"],
        "End Node":["XX"],
        "Has Path":[false],
        "Comment":"Capability 1 not possible"
        }
            },
            {"Degraded bin 1":{
        "Begin Node":["X_1"],
        "End Node":["Generator Control Panel"],
        "Has Path":[false],
        "Comment":"Capability 1 degraded state 1"
        }
            },
            {"Degraded bin 2":{
        "Begin Node":["X_1"],
        "End Node":["XX_2"],
        "Has Path":[false],
        "Comment":"Capability 1 degraded state 2"
```

```
        }
            }
        ]
    },

    "SOS Structure":{
        "Admin Nodes":[],
        "Terminal Nodes":["X", "XX"],
        "Edges":{
            "X":["X_1"],
            "XX_1":["X_2"],
            "XX_2":["XX"]
        },
        "Capability Edges":{
           "AA_1":["DD_2"],
           "BB_1":["CC_2"]
        }
    }

}
```

E.2.4.2 Scenario Data Files

In addition to the file listing shown here, unit testing of the EnvTools package also employed the `Demo.scdf.json` file used in the SOS package tests.

Listing E.36: The MCNP_demo analytical scenario data file (MCNP_demo.scdf.json)

```
{
    "HEADER COMMENTS":"The following data provides physical and temporal information governing weapon prameters and SOS layout for use by NuSCAP.",
  "Prefix":"C:\\temp\\Demo_SOS\\",
  "Name":"Tiny_Demo",
    "MCNP path":"C:\\MCNP62\\MCNP_CODE\\bin\\mcnp6",
    "MCNP datapath":"C:\\MCNP62\\MCNP_DATA",
    "MCNP threads":8,
    "SNEC path":"C:\\Users\\339528\\Documents\\Git\\NuSCAP\\NuSCAP\\JSL\\JSL_5.6\\Dist_2\\Combined_JSL_5.6_Distro\\Java Tools for Windows\\WebMultipleEffects",
    "GIS and Weather Data":{
        "GIS Reference Datum": "WGS84",
        "Ground Zero Location": "15S UU 88400 91100",
        "Ground Zero Elevation (MSL) [m]": 199,
        "DTG":"23 1200Z AUG 1987",
        "Atmospheric Visibility [km]": 50
    },
    "Threat Weapon Data":{
        "Weapon Type":"Fission Only",
        "Fission Fraction": 1,
        "Yield [kt]": 10.0,
        "HOB [m]": 150.0,
        "HOB sigma [m]":0,
        "CEP [m]": 0,
        "NPS":1E4,
        "Neutron Leakage Spectrum":{
            "neutron yield [mol/kt]": 0.264,
            "si option":"H",
            "energy bins [MeV]":[
                1.00E-16, 1.00E-11, 5.00E-10, 2.00E-9, 5.00E-9, 1.00E-8, 1.45E-8, 2.10E-8,
                3.00E-8, 4.00E-8, 5.00E-8, 7.00E-8, 1.00E-7, 1.25E-7, 1.50E-7, 1.84E-7,
                2.25E-7, 2.75E-7, 3.25E-7, 3.67E-7, 4.14E-7, 5.00E-7, 5.32E-7, 6.25E-7,
                6.83E-7, 8.00E-7, 8.67E-7, 1.00E-6, 1.04E-6, 1.08E-6, 1.13E-6, 1.30E-6,
                1.45E-6, 1.86E-6, 2.38E-6, 3.06E-6, 3.93E-6, 5.04E-6, 6.48E-6, 8.32E-6,
                1.07E-5, 1.37E-5, 1.76E-5, 2.26E-5, 2.90E-5, 3.73E-5, 4.79E-5, 6.14E-5,
                7.89E-5, 1.01E-4, 1.30E-4, 1.67E-4, 2.14E-4, 2.75E-4, 3.54E-4, 4.54E-4,
                5.83E-4, 7.49E-4, 9.61E-4, 1.23E-3, 1.58E-3, 2.03E-3, 2.25E-3, 2.49E-3,
                2.61E-3, 2.75E-3, 3.04E-3, 3.35E-3, 3.71E-3, 4.31E-3, 5.53E-3, 7.10E-3,
                9.12E-3, 1.06E-2, 1.17E-2, 1.50E-2, 1.93E-2, 2.19E-2, 2.36E-2, 2.42E-2,
                2.48E-2, 2.61E-2, 2.70E-2, 2.85E-2, 3.18E-2, 3.43E-2, 4.09E-2, 4.63E-2,
                5.25E-2, 5.66E-2, 6.74E-2, 7.20E-2, 7.95E-2, 8.25E-2, 8.65E-2, 9.80E-2,
                1.11E-1, 1.17E-1, 1.23E-1, 1.29E-1, 1.36E-1, 1.43E-1, 1.50E-1, 1.58E-1,
                1.66E-1, 1.74E-1, 1.83E-1, 1.93E-1, 2.02E-1, 2.13E-1, 2.24E-1, 2.35E-1,
                2.47E-1, 2.73E-1, 2.87E-1, 2.95E-1, 2.97E-1, 2.98E-1, 3.02E-1, 3.34E-1,
                3.69E-1, 3.88E-1, 4.08E-1, 4.50E-1, 4.98E-1, 5.23E-1, 5.50E-1, 5.78E-1,
                6.08E-1, 6.39E-1, 6.72E-1, 7.07E-1, 7.43E-1, 7.81E-1, 8.21E-1, 8.63E-1,
                9.07E-1, 9.62E-1, 1.00, 1.11, 1.16, 1.22, 1.29, 1.35, 1.42, 1.50, 1.57,
                1.65, 1.74, 1.83, 1.92, 2.02, 2.12, 2.23, 2.31, 2.35, 2.37, 2.39, 2.47,
                2.59, 2.73, 2.87, 3.01, 3.17, 3.33, 3.68, 4.07, 4.49, 4.72, 4.97, 5.23,
```

```
                5.49, 5.77, 6.07, 6.38, 6.59, 6.70, 7.05, 7.41, 7.79, 8.19, 8.61, 9.05,
                9.51, 10.0, 10.5, 11.1, 11.6, 12.2, 12.5, 12.8, 13.5, 13.8, 14.2, 14.6,
                14.9, 15.7, 16.5, 16.9, 17.3, 20.0
            ],
            "sp option":"D",
            "probability [mol/MeV-kt]":[
                0, 1.00E-9, 2.04E-11, 6.67E-12, 3.33E-12, 2.00E-12, 2.22E-12, 1.78, 2.75, 3.07,
                5.95, 12.7, 15.5, 22.8, 31.9, 23.9, 46.0, 44.1, 59.2, 75.7, 64.2, 80.9, 99.7,
                1.00E2, 111, 139, 159, 170, 174, 197, 182, 218, 235, 271, 339, 410, 512, 616,
                748, 886, 1.04E3, 1.19E3, 1.34E3, 1.45E3, 1.52E3, 1.54E3, 1.48E3, 1.36E3,
                1.19E3, 996, 794, 614, 462, 334, 228, 141, 74.8, 33.3, 12.4, 3.84, 1.02,
                2.26E-1, 7.77E-2, 6.15E-2, 4.43E-2, 3.12E-2, 3.34E-2, 2.52E-2, 2.17E-2, 1.67E-2,
                1.40E-2, 1.08E-2, 8.59E-3, 6.76E-3, 5.36E-3, 5.23E-3, 4.57E-3, 4.19E-3, 4.43E-3,
                4.53E-3, 4.36E-3, 4.87E-3, 4.89E-3, 1.20E-3, 1.42E-3, 1.31E-3, 1.13E-3, 1.92E-3,
                1.76E-3, 1.65E-3, 1.79E-3, 2.17E-3, 1.70E-3, 1.30E-3, 5.97E-4, 8.85E-4, 1.16E-3,
                1.33E-3, 1.01E-3, 1.55E-3, 1.44E-3, 8.63E-4, 6.13E-4, 7.12E-4, 8.11E-4, 9.41E-4,
                1.04E-3, 9.16E-4, 7.07E-4, 6.42E-4, 7.43E-4, 7.87E-4, 8.82E-4, 9.11E-4, 7.03E-4,
                7.30E-4, 8.21E-4, 6.02E-4, 7.36E-4, 6.93E-4, 7.46E-4, 6.05E-4, 6.61E-4, 4.35E-4,
                6.21E-4, 6.59E-4, 6.69E-4, 6.71E-4, 7.90E-4, 7.04E-4, 6.70E-4, 6.48E-4, 6.64E-4,
                6.06E-4, 5.40E-4, 5.52E-4, 4.98E-4, 4.85E-4, 3.69E-4, 3.88E-4, 4.68E-4, 4.65E-4,
                4.67E-4, 3.91E-4, 4.46E-4, 4.48E-4, 4.17E-4, 3.76E-4, 4.15E-4, 3.74E-4, 3.37E-4,
                3.39E-4, 3.51E-4, 3.54E-4, 3.70E-4, 4.51E-4, 4.31E-4, 4.45E-4, 3.63E-4, 2.79E-4,
                2.60E-4, 2.27E-4, 1.84E-4, 1.83E-4, 1.16E-4, 9.70E-5, 9.33E-5, 8.52E-5, 1.00E-4,
                9.49E-5, 7.73E-5, 6.52E-5, 5.32E-5, 5.05E-5, 3.92E-5, 3.45E-5, 3.18E-5, 3.03E-5,
                1.79E-5, 1.26E-5, 9.18E-6, 1.02E-5, 6.88E-6, 5.81E-6, 3.17E-6, 2.07E-6, 1.75E-6,
                1.29E-6, 9.17E-7, 3.68E-7, 4.17E-7, 1.96E-7, 8.11E-8, 2.01E-7, 1.63E-7, 2.43E-7,
                1.05E-7, 3.11E-8, 6.58E-8, 0, 2.86E-8
            ],
            "reference":"LA-UR-13-26113, Table 6"
        },
        "Neutron Response Functions":{
            "Human":{
                "Energy [MeV]":[
                    2.5E-8, 1.0E-7, 1.0E-6, 1.0E-5, 1.0E-4, 1.0E-3, 0.01, 0.1, 0.5, 1.0, 2.5, 5.0,
                    7.0, 10.0, 14.0, 20.0
                ],
                "Conversion Factor":{
                    "units":"[(rem/hr)/(cm$^{-2}\\cdot$s$^{-1}$)",
                    "values":
                    [
                    3.67E-6, 3.67E-6, 4.46E-6, 4.54E-6, 4.18E-6, 3.76E-6, 3.56E-6, 2.17E-5, 9.26E-5,
                    1.32E-4, 1.25E-4, 1.56E-4, 1.47E-4, 1.47E-4, 2.08E-4, 2.27E-4
                    ]
                    },
                "Quality Factor":[
                    2.0, 2.0, 2.0, 2.0, 2.0, 2.0, 2.5, 7.5, 11.0, 11.0, 9.0, 8.0, 7.0, 6.5, 7.5, 8.0
                ],
                "reference":"ANSI/ANS-6.1.1-1977, Table 1"
            },
            "Equipment":{
                "Fluence":{
                    "Energy [MeV]":[
                        1.38880E-10, 1.00000E-09, 5.00000E-09, 1.00000E-08, 3.00000E-08, 7.00000E-08,
                        1.00000E-07, 1.52300E-07, 2.00000E-07, 4.13990E-07, 6.00000E-07, 8.00000E-07,
                        1.12530E-06, 3.05900E-06, 5.04350E-06, 8.31530E-06, 1.37100E-05, 2.26030E-05,
                        3.72660E-05, 6.14420E-05, 1.01300E-04, 1.67020E-04, 2.75360E-04, 3.53580E-04,
                        4.54000E-04, 5.82950E-04, 7.48520E-04, 9.61120E-04, 1.08910E-03, 1.23410E-03,
```

```
                        1.39840E-03, 1.58460E-03, 1.79560E-03, 2.03470E-03, 2.30560E-03, 2.61260E-03,
                        2.96040E-03, 3.35460E-03, 3.80130E-03, 4.30740E-03, 4.88100E-03, 5.53080E-03,
                        6.26730E-03, 7.10170E-03, 8.04730E-03, 9.11880E-03, 1.03330E-02, 1.17090E-02,
                        1.32680E-02, 1.50340E-02, 1.70360E-02, 1.93040E-02, 2.18750E-02, 2.47880E-02,
                        2.60580E-02, 2.80880E-02, 3.18280E-02, 4.08680E-02, 5.24750E-02, 6.73790E-02,
                        8.65170E-02, 1.11090E-01, 1.42640E-01, 1.83160E-01, 2.35180E-01, 3.01970E-01,
                        3.87740E-01, 4.39370E-01, 4.97870E-01, 5.64160E-01, 6.39280E-01, 7.24400E-01,
                        8.20850E-01, 9.30140E-01, 1.05400E00, 1.19430E00, 1.35340E00, 1.73770E00,
                        2.23130E00, 2.86510E00, 3.67880E00, 4.72370E00, 6.06530E00, 7.78800E00,
                        1.00000E01, 1.19120E01, 1.34990E01, 1.49180E01, 1.69050E01, 2.00000E01
                    ],
                    "Conversion Factor":{
                        "units":"1-MeV neutron Equivalent Fluence",
                        "values":
                        [
                        0.000000, 7.38697E-03, 3.13312E-03, 1.87815E-03, 1.17364E-03, 7.32402E-04,
                        5.52298E-04, 4.53680E-04, 3.83152E-04, 2.93933E-04, 2.26408E-04, 1.92229E-04,
                        1.64111E-04, 1.14214E-04, 8.03363E-05, 6.25425E-05, 4.87135E-05, 3.79357E-05,
                        2.95522E-05, 2.30102E-05, 1.79240E-05, 1.39594E-05, 3.00309E-04, 5.55850E-04,
                        6.65494E-04, 7.68969E-04, 9.10440E-04, 1.10621E-03, 1.29490E-03, 1.44634E-03,
                        1.60935E-03, 1.80074E-03, 2.01916E-03, 2.27304E-03, 3.26010E-03, 2.87101E-03,
                        3.21528E-03, 3.61954E-03, 4.06547E-03, 4.58726E-03, 5.22228E-03, 5.83754E-03,
                        6.49984E-03, 7.30252E-03, 8.18355E-03, 9.18417E-03, 1.02944E-02, 1.15055E-02,
                        1.28715E-02, 1.43322E-02, 1.63567E-02, 1.77608E-02, 1.96045E-02, 2.16808E-02,
                        2.30574E-02, 2.40674E-02, 2.58766E-02, 2.95862E-02, 2.53388E-02, 1.44824E-01,
                        6.03347E-02, 4.99138E-02, 2.51383E-02, 3.30996E-01, 9.39793E-01, 5.87161E-01,
                        5.27088E-01, 5.51634E-01, 5.74569E-01, 8.18293E-01, 6.84671E-01, 5.99507E-01,
                        9.58147E-01, 1.02449E+00, 1.02066E+00, 7.14611E-01, 9.53149E-01, 1.23834E+00,
                        1.18819E+00, 1.24346E+00, 1.21600E+00, 1.44917E+00, 1.66224E+00, 1.69987E+00,
                        1.80733E+00, 1.79803E+00, 1.88335E+00, 1.88105E+00, 1.94630E+00, 2.04731E+00
                        ]
                    },
                    "reference":"SAND2016-5511, Appendix B"
                },
            "Dose":{
    "units":"[rad (Si)]",
    "values":"3.3450364E-10  3  -4  1",
    "reference":"MatMCNP, Russ DePriest"
      }
        }
        },
        "Photon Leakage Spectrum":{
            "photon yield [mol/kt]":9.02E-2,
            "si option":"H",
            "energy bins [MeV]":[
                0.001, 0.010, 0.020, 0.030, 0.040, 0.045, 0.060, 0.070, 0.075, 0.100, 0.150,
                0.200, 0.300, 0.400, 0.450, 0.510, 0.512, 0.600, 0.700, 0.800, 1.000, 1.330,
                1.340, 1.500, 1.660, 2.000, 2.500, 3.000, 3.500, 4.000, 4.500, 5.000, 5.500,
                6.000, 6.500, 7.000, 7.500, 8.000, 10.000, 12.000, 14.000, 20.000, 30.000
            ],
            "sp option":"D",
            "probability [mol/MeV-kt]":[
                0, 4.43E-4, 8.51E-4, 7.53E-4, 1.39E-3, 2.25E-3, 5.86E-3, 1.72E-2, 2.38E-2,
                5.85E-2, 8.00E-2, 7.46E-2, 7.76E-2, 5.83E-2, 5.48E-2, 6.76E-2, 3.85E-1, 7.32E-2,
                4.00E-2, 3.35E-2, 3.08E-2, 2.34E-2, 1.90E-2, 2.07E-2, 1.84E-2, 1.66E-2, 1.59E-2,
                7.66E-3, 4.25E-3, 5.43E-3, 2.58E-3, 6.75E-4, 5.44E-4, 4.29E-4, 3.55E-4, 3.50E-4,
                1.20E-4, 9.42E-4, 2.79E-5, 9.69E-6, 3.38E-8, 1.67E-13, 0
```

```
            ],
            "reference":"LA-UR-13-26113, Table 7"
        },
        "Photon Response Functions":{
            "Human":{
            "Energy [MeV]":[
                0.01, 0.03, 0.05, 0.07, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6,
                0.65, 0.7, 0.8, 1.0, 1.4, 1.8, 2.2, 2.6, 2.8, 3.25, 3.75, 4.25, 4.75, 5.0, 5.25,
                5.75, 6.25, 6.75, 7.5, 9.0, 11.0, 13.0, 15.0
            ],
            "Conversion Factor":{
                "units":"[(rem/hr)/(cm$^{-2}\\cdot$s$^{-1}$)",
                "values":
                [
                3.96E-6, 5.82E-7, 2.9E-7, 2.58E-7, 2.83E-7, 3.79E-7, 5.01E-7, 6.31E-7, 7.59E-7,
                8.78E-7, 9.85E-7, 1.08E-6, 1.11E-6, 1.27E-6, 1.36E-6, 1.44E-6, 1.52E-6, 1.68E-6,
                1.98E-6, 2.51E-6, 2.99E-6, 3.42E-6, 3.82E-6, 4.01E-6, 4.41E-6, 4.83E-6, 5.23E-6,
                5.6E-6, 5.8E-6, 6.01E-6, 6.37E-6, 6.74E-6, 7.11E-6, 7.66E-6, 8.77E-6, 1.03E-5,
                1.18E-5, 1.33E-5
                ]
            },
            "reference":"ANSI/ANS-6.1.1-1977, Table 3"
            },
            "Equipment":{
    "units":"[rad (Si)]",
    "values":"3.4350364E-10  3  -5  -6",
    "reference":"MatMCNP, Russ DePriest"
      }
        }
    },

    "Systems Data":{

        "System 1":{
          "GIS Data":{
            "Location (MGRS)": "15S UU 89400 91100",
            "Elevation (MSL) [m]": 192,
                "R95 [km]": 0,
                "Depth [m]":0,
            "Heading [grid deg]": 0
            }
        },

        "System 2":{
          "GIS Data":{
            "Location (MGRS)": "15S UU 88400 92100",
            "Elevation (MSL) [m]":188,
                "R95 [km]": 0,
                "Depth [m]":0,
            "Heading [grid deg]": 90
            }

        }
    },

    "Transport Materials":{
        "Surface":{
```

```
            "Name":"Earth, U.S. Average",
            "Density [g/cm^3]":1.52,
            "Composition":{
                "8016":-0.512323,
                "8017":-0.000207,
                "11023":-0.006140,
                "12000":-0.013304,
                "13027":-0.068564,
                "14000":-0.271180,
                "19000":-0.014327,
                "20000":-0.051166,
                "22000":-0.004604,
                "25055":-0.000715,
                "26000":-0.056285
            },
            "Notes":"PNNL-15870, Rev. 2, O-18 neglected to permit ENDF/B-VII use"
        },
        "Atmosphere":{
            "Name":"Air (dry, near sea level)",
            "Density [g/cm^3]":0.001205,
            "Composition":{
                "6000":-0.000124,
                "7014":-0.752316,
                "7015":-0.002944,
                "8016":-0.231153,
                "8017":-0.000094,
                "18000":-0.012827
            },
            "Notes":"PNNL-15870, Rev. 2, O-18 neglected to permit ENDF/B-VII use"
        },
        "Detector":{

            "Name":"Silicon",
            "Density [g/cm^3]":2.33,
            "Composition":{
                "14028":0.92223,
                "14029":0.04685,
                "14030":0.03092
            },
            "Notes":"Nuclear Wallet Cards - Electronic Version, provided by Russ DePriest"
        }
    },

  "Developer Name":"R. Boone Gilbreath",
    "Developer Title":"Major, U.S. Army",
    "Developer Organization":"Radiation Transport Applications Group, Los Alamos National Laboratory",

  "Maintainer":"R. Boone Gilbreath",
    "Maintainer Title":"Major, U.S. Army",
    "Maintainer Organization":"Radiation Transport Applications Group, Los Alamos National Laboratory"
}
```

E.2.4.3 System Data Files

In addition to the file listings shown here, unit testing of the EnvTools package also employed the `SYS_1.sdf.json`, `SYS_2.sdf.json`, `SYS_3.sdf.json`, `SYS_5_1.sdf.json`, and `SYS_5_2.sdf.json` files used in the SOS package tests.

Listing E.37: The SYS_1 system data file for the Tiny system of systems (SYS_1.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 1 of the Demonstration SOS",
  "System":{
        "System 1":{
        "ID": "System 1",

        "VNTK": "null",

        "type":"equipment",
                    "color": "#0070C1",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

        "Subsystem B1":{

     "ID":"B_1",

     "type":"equipment",

     "relative position":[1,1,0],

     "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
```

```
      },
      "Components":{
        "Soldier 1":{
          "ID":"SM_1",
          "type":"human",
          "relative position":[2,2,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        },
                "Generator Control Panel":{
          "ID":"GEN_CTRL",
          "type":"equipment",
          "relative position":[-1,-1,0],
          "thresholds":{
            "static overpressure": "inf",
            "dynamic pressure": "inf",
            "windspeed": 1,
            "thermal fluence": "inf",
            "total dose": "inf",
            "neutron dose": "inf",
            "neutron fluence": "inf",
            "gamma ray dose": "inf",
            "gamma ray dose rate": "inf",
            "PD": "inf"}
        }
                }
            }    },

  "capabilities":{
    "Capability 1":[
            {"100% bin":{
        "Begin Node":["X_1"],
        "End Node":["BB_1"],
        "Has Path":[true],
        "Comment":"Capability 1 present"
          }
            },
            {"NOT POSSIBLE":{
        "Begin Node":["X_1"],
        "End Node":["BB_1"],
        "Has Path":[false],
        "Comment":"Capability 1 not present"
                }
            },
      {"Degraded bin":{
        "Begin Node":["X_1"],
        "End Node":["AA_1"],
        "Has Path":[true],
```

```
        "Comment":"Capability 1 degraded"
                }
            }
        ]
  },

  "Structure":{
    "Admin Nodes":["AA_1", "BB_1"],
        "Terminal Nodes":["X_1","XX_1"],
    "Edges":{
            "X_1":["System 1"],
            "System 1":["AA_1"],
            "AA_1":["Subsystem B1"],
            "Subsystem B1":["Soldier 1", "Generator Control Panel"],
            "Generator Control Panel":["BB_1"],
            "Soldier 1":["BB_1"],
            "BB_1":["XX_1"]

    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
     Laboratory",
  "Date":"5 MAY 23",
  "Maintainer":"R. Boone Gilbreath"
}
```

Listing E.38: The SYS_2 system data file for the MCNP_demo system of systems (SYS_2.sdf.json)

```
{
  "HEADER COMMENTS":"SDF for System 2 of the Demonstration SOS",
  "System":{

        "System 2":{

        "ID": "System 2",

        "type":"equipment",
                    "color": "#E17800",

        "VNTK": "null",

        "thresholds":{
          "static overpressure": "inf",
          "dynamic pressure": "inf",
          "windspeed": "inf",
          "thermal fluence": "inf",
          "total dose": "inf",
          "neutron dose": "inf",
          "neutron fluence": "inf",
          "gamma ray dose": "inf",
          "gamma ray dose rate": "inf",
          "PD": "inf"
        }
        }
  },

  "Subsystems":{

    "Subsystem C2":{

      "ID":"C_2",

      "type":"equipment",

      "relative position":[1,1,0],

      "thresholds":{
        "static overpressure": "inf",
        "dynamic pressure": "inf",
        "windspeed": "inf",
        "thermal fluence": "inf",
        "total dose": "inf",
        "neutron dose": "inf",
        "neutron fluence": "inf",
        "gamma ray dose": "inf",
        "gamma ray dose rate": "inf",
        "PD": "inf"
      },
      "Components":{
                    "RWCIU 2":{
                          "ID":"RWCIU_2",
          "type":"equipment",
          "relative position":[2,1,0],
                          "thresholds":{
```

```
                              "static overpressure": "inf",
                    "dynamic pressure": "inf",
                    "windspeed": 9,
                    "thermal fluence": "inf",
                    "total dose": "inf",
                    "neutron dose": "inf",
                    "neutron fluence": "inf",
                    "gamma ray dose": "inf",
                    "gamma ray dose rate": "inf",
                    "PD": "inf"
                      }
                  }
              }
          }
    },

  "capabilities":{
    "Communicates with System 1":[
             {"Communicates via Data Cable":{
          "Begin Node":["X_2"],
          "End Node":["DD_2"],
          "Has Path":[true],
          "Comment":"Communicates via data cable"
          }
              },
              {"NOT POSSIBLE":{
          "Begin Node":["X_2"],
          "End Node":["DD_2"],
          "Has Path":[false],
          "Comment":"Cannot communicate with System 1"
          }
              }
          ]
    },

  "Structure":{
    "Admin Nodes":["CC_2", "DD_2"],
        "Terminal Nodes":["X_2","XX_2"],
    "Edges":{
              "X_2":["System 2"],
              "System 2":["Subsystem C2"],
              "Subsystem C2":["CC_2"],
              "CC_2":["RWCIU 2"],
              "RWCIU 2":["DD_2"],
              "DD_2":["XX_2"]
    }
  },

  "Developer":"R. Boone Gilbreath, MAJ, USA, Radiation Transport Applications Group, Los Alamos National
      Laboratory",
  "Date":"1 NOV 22",
  "Maintainer":"R. Boone Gilbreath"
}
```

Appendix F

Case Study Data

This appendix includes system and SOS graphs used in the case study. Subsequently, the listings contained in this appendix compose the input data files along with the resulting reports and SOS-level graphs produced during the NuSCAP proof-of-concept case study presented in chapter 5.

All file listings are attached to the electronic PDF version of this document.

F.1 Complete SOS Graph

Figure F.1 depicts the complete SOS-level graph used in the case study. Terminal nodes are white, rounded rectangles. Blue-gray lozenges represent administrative nodes. Elemental nodes are rectangular and colored to differentiate between system types. Blue nodes belong to the command and control system. Orange nodes represent those of the target sensor system. Red nodes indicate belonging to the electric power plant system. Green nodes compose the six weapon systems. Logical connections within a system are depicted by black edges while inter-system capability edges are shown in orange.

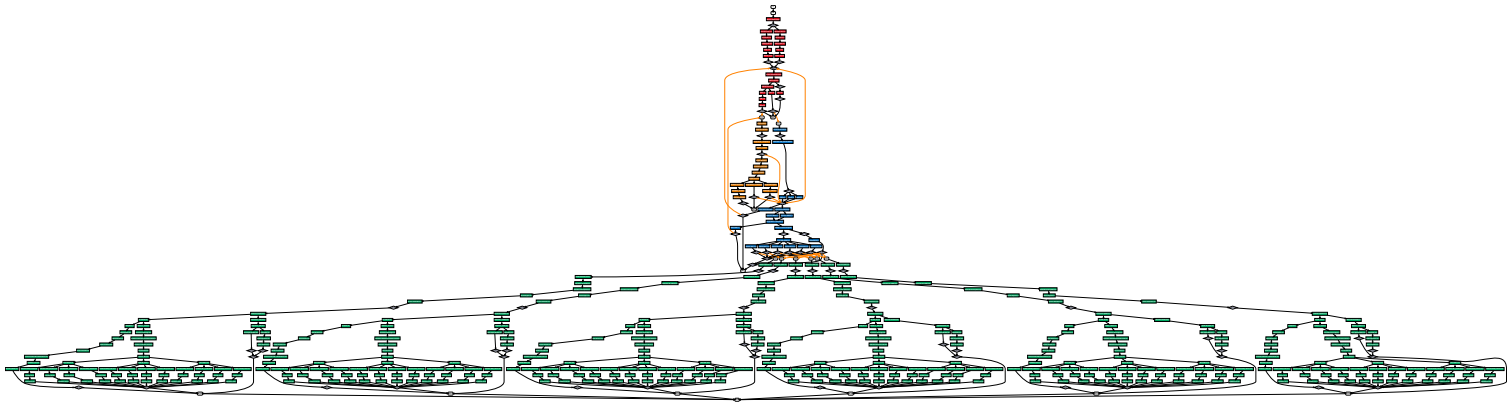


Figure F.1: The complete case study SOS graph.

F.2 Individual System Graphs

The figures F.2–F.5 depict individual system graphs for the SOS analyzed in the case study. Coloring conventions are the same as those provided in appendix F.1.

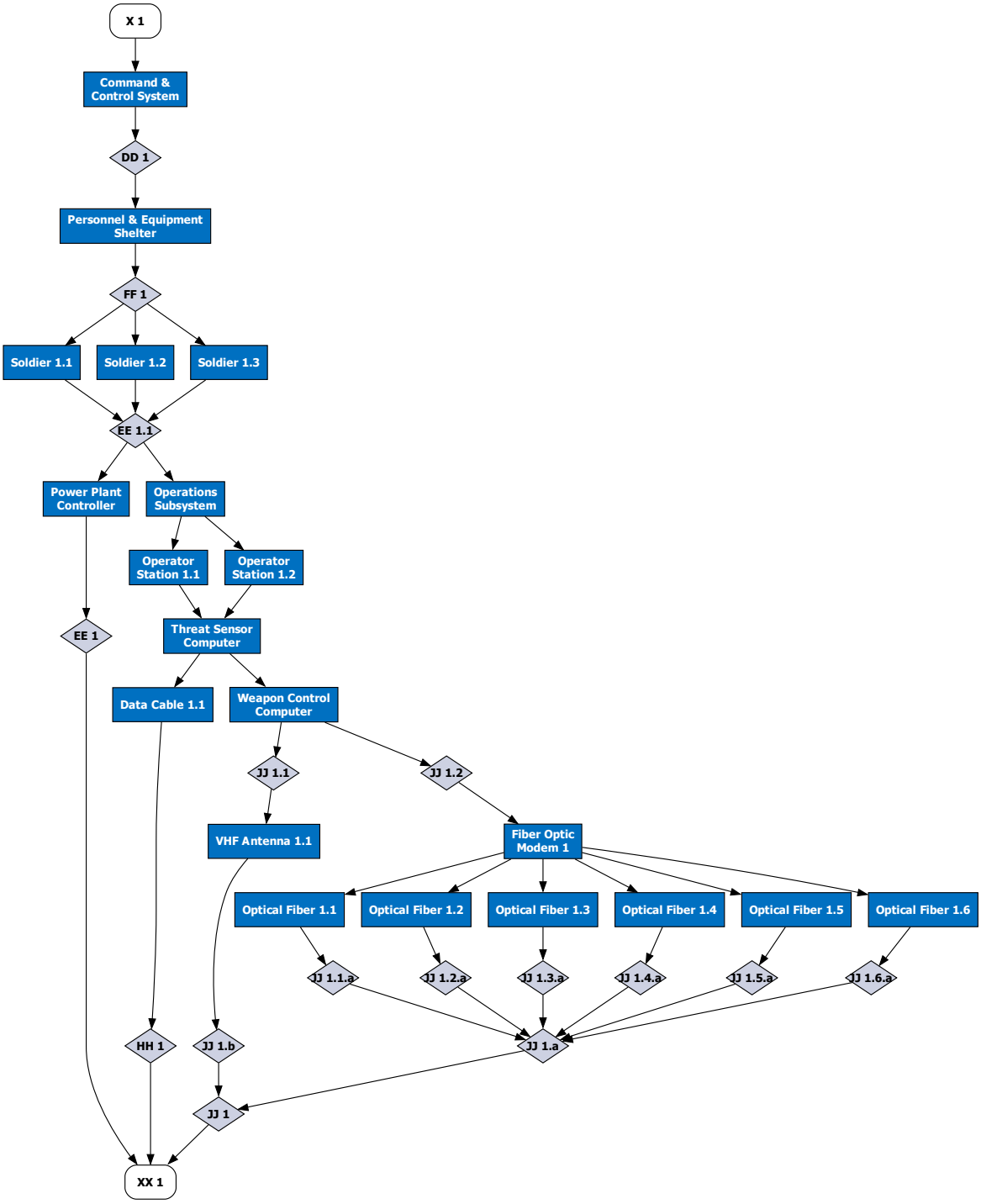


Figure F.2: System 1 (command and control system) graph.

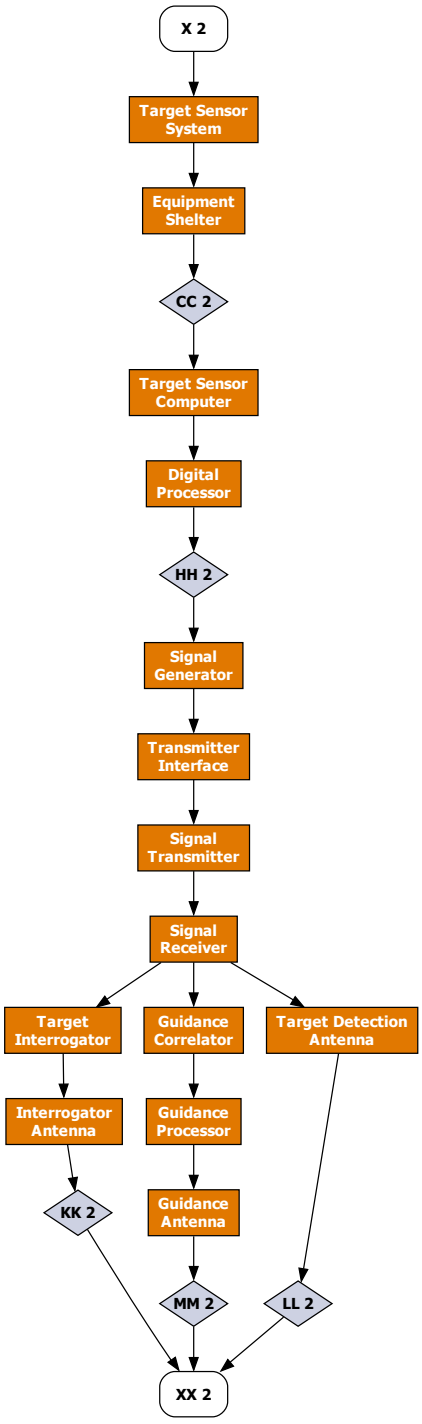


Figure F.3: System 2 (target sensor system) graph.

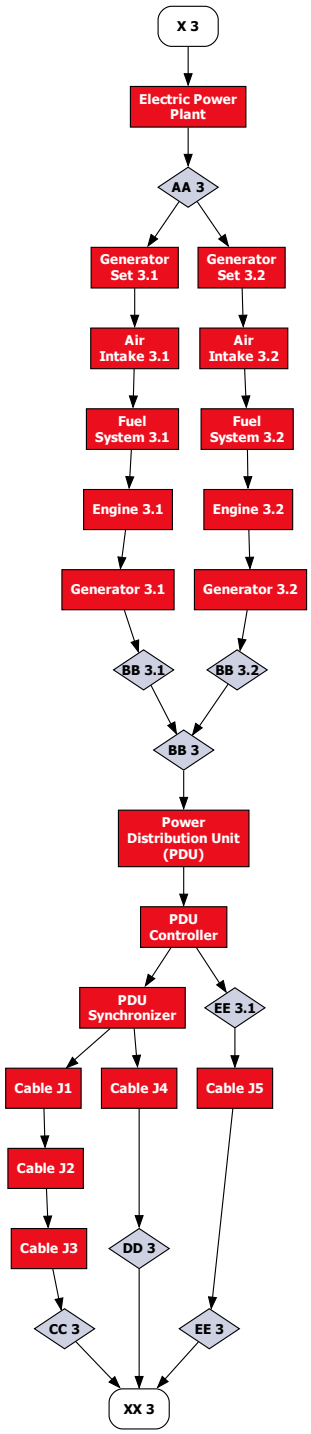


Figure F.4: System 3 (electric power plant system) graph.

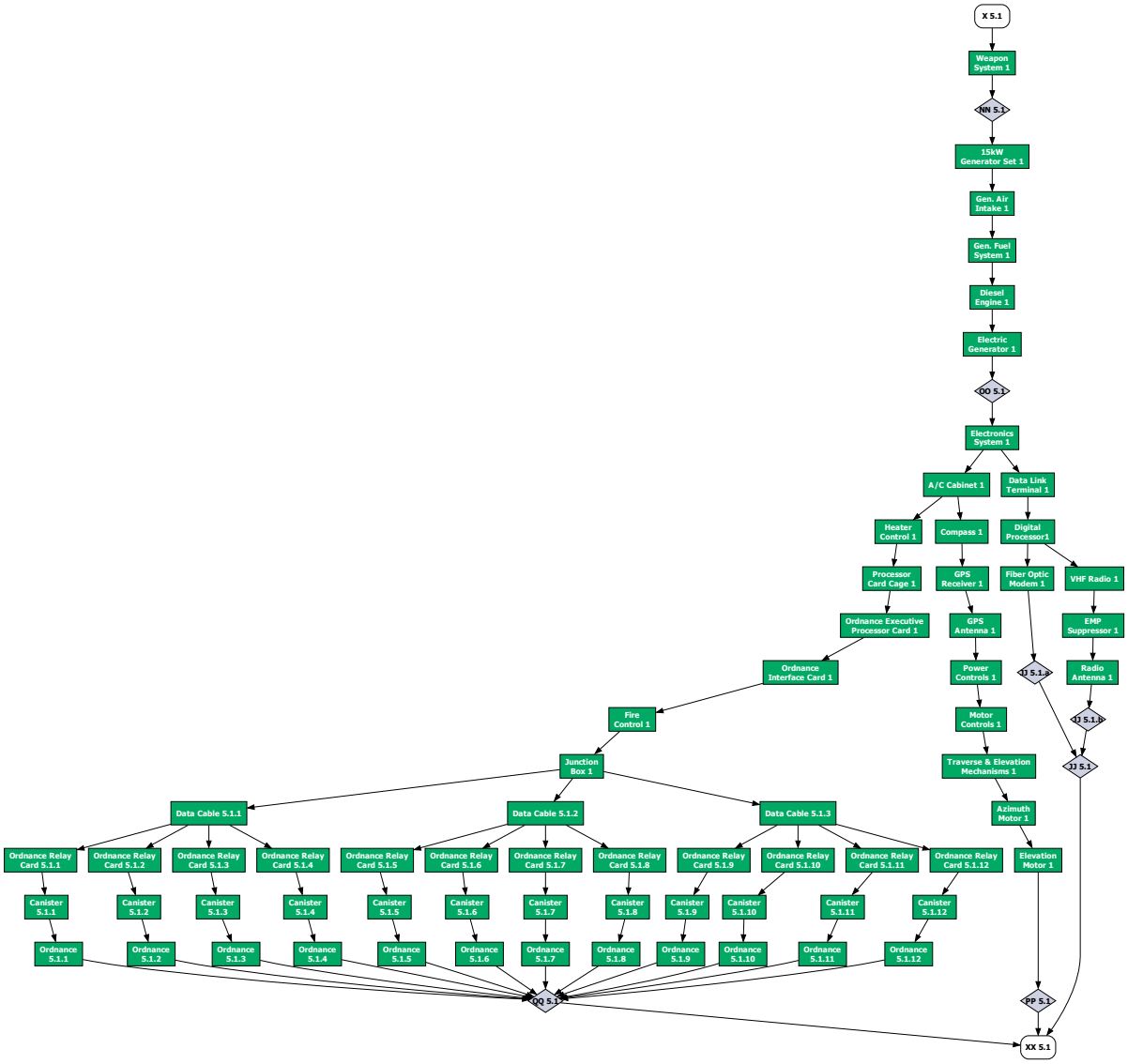


Figure F.5: System 5.1 (weapon system) graph.
Note: Graphs of all six weapon systems are identical.

F.3 User-Generated Input Files

The user-generated input files here define a representative, conventional, US Army SOS specified by the sponsors of this work herein referred to as Reference. Aside from the values otherwise qualified in chapter 5, the threshold values presented here do not represent dysfunction levels for any actual component, subsystem, or system. They are used here as illustrative values to demonstrate the utility of the NuSCAP method and application. The SOS is modeled in three damage regimes as defined by the analytical scenario data files included in this section.

F.3.1 SOS Data File

Listing F.1: The Reference system-of-systems data file for the case study scenarios (Reference.sosdf.json)

```
{
    "HEADER COMMENTS": "The case study SOS prepared as a proof of concept for the NuSCAP method and Applications",
    "System of Systems": {
        "Reference": {
    "ID": "Case Study SOS"
  }
    },
    "Systems": {
        "Command & Control": {"SDF Path": "C:\\Users\\339528\\Documents\\Git\\NuSCAP\\Users\\Gilbreath\\Systems\\Command_and_Control.sdf.json"},
        "Target Sensor": {"SDF Path": "C:\\Users\\339528\\Documents\\Git\\NuSCAP\\Users\\Gilbreath\\Systems\\Target_Sensor.sdf.json"},
        "Electric Power Plant": {"SDF Path": "C:\\Users\\339528\\Documents\\Git\\NuSCAP\\Users\\Gilbreath\\Systems\\Electric_Power_Plant.sdf.json"},
        "Weapon System 5.1": {"SDF Path": "C:\\Users\\339528\\Documents\\Git\\NuSCAP\\Users\\Gilbreath\\Systems\\Weapon_System_1.sdf.json"},
        "Weapon System 5.2": {"SDF Path": "C:\\Users\\339528\\Documents\\Git\\NuSCAP\\Users\\Gilbreath\\Systems\\Weapon_System_2.sdf.json"},
        "Weapon System 5.3": {"SDF Path": "C:\\Users\\339528\\Documents\\Git\\NuSCAP\\Users\\Gilbreath\\Systems\\Weapon_System_3.sdf.json"},
        "Weapon System 5.4": {"SDF Path": "C:\\Users\\339528\\Documents\\Git\\NuSCAP\\Users\\Gilbreath\\Systems\\Weapon_System_4.sdf.json"},
        "Weapon System 5.5": {"SDF Path": "C:\\Users\\339528\\Documents\\Git\\NuSCAP\\Users\\Gilbreath\\Systems\\Weapon_System_5.sdf.json"},
        "Weapon System 5.6": {"SDF Path": "C:\\Users\\339528\\Documents\\Git\\NuSCAP\\Users\\Gilbreath\\Systems\\Weapon_System_6.sdf.json"}
    },
    "SOS capabilities": {
        "Power Prime Systems": [
            {
                "Powers C2 & Target Sensor": {
                    "Begin Node": ["X 3", "X 3"],
                    "End Node": ["DD 1", "CC 2"],
                    "Has Path": [true, true],
                    "Comment": "Powers Command & Control and Target Sensor systems"
                }
```

```
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": ["X 3", "X 3"],
                    "End Node": ["DD 1", "CC 2"],
                    "Has Path": [false, false],
                    "Comment": "Can NOT power Command & Control or Target Sensor system"
                }
            },
            {
                "Powers Target Sensor System ONLY": {
                    "Begin Node": ["X 3", "X 3"],
                    "End Node": ["DD 1", "CC 2"],
                    "Has Path": [false, true],
                    "Comment": "Powers Target Sensor system ONLY"
                }
            },
            {
                "Powers Command & Control system ONLY": {
                    "Begin Node": ["X 3", "X 3"],
                    "End Node": ["DD 1", "CC 2"],
                    "Has Path": [true, false],
                    "Comment": "Powers Command & Control system ONLY"
                }
            }
        ],
        "Control Electric Power Plant": [
            {
                "Remote and Local Control Possible": {
                    "Begin Node": ["X 1", "X 1", "X 3"],
                    "End Node": ["EE 3", "EE 1.1", "EE 3.1"],
                    "Has Path": [true, true, true],
                    "Comment": "Electric Power Plant control available by remote and local control panel
    "
                }
            },
            {
                "NOT POSSIBLE 1": {
                    "Begin Node": ["X 1", "X 3"],
                    "End Node": ["EE 3.1", "EE 3"],
                    "Has Path": [false, false],
                    "Comment": "Can NOT control Electric Power Plant"
                }
            },
            {
                "NOT POSSIBLE 2": {
                    "Begin Node": ["X 3"],
                    "End Node": ["DD 1"],
                    "Has Path": [false],
                    "Comment": "Can NOT control Electric Power Plant"
                }
            },
            {
                "Local Control": {
                    "Begin Node": ["X 1", "X 1", "X 3"],
                    "End Node": ["EE 3", "EE 1.1", "EE 3.1"],
                    "Has Path": [false, true, false],
```

```
                    "Comment": "Electric Power Plant control available by local control panel ONLY"
                }
            }
    ],
        "Acquire Targets": [
            {
                "Senses and Identifies Targets": {
                    "Begin Node": ["X 1", "HH 1", "X 2", "X 3", "X 3", "X 2", "X 2"],
                    "End Node": ["HH 1", "HH 2", "HH 1", "CC 2", "DD 1", "KK 2", "LL 2"],
                    "Has Path": [true, true, true, true, true, true, true],
                    "Comment": "System senses targets and identifes as friend/foe"
                }
            },
            {
                "NOT POSSIBLE 1": {
                    "Begin Node": ["X 3"],
                    "End Node": ["CC 2"],
                    "Has Path": [false],
                    "Comment": "Target Sensor can NOT sense or identify targets"
                }
            },
        {
                "NOT POSSIBLE 2": {
                    "Begin Node": ["X 3"],
                    "End Node": ["DD 1"],
                    "Has Path": [false],
                    "Comment": "Target Sensor can NOT sense or identify targets"
                }
            },
        {
                "NOT POSSIBLE 3": {
                    "Begin Node": ["X 2", "X 2"],
                    "End Node": ["KK 2", "LL 2"],
                    "Has Path": [false, false],
                    "Comment": "Target Sensor can NOT sense or identify targets"
                }
            },
        {
                "NOT POSSIBLE 4": {
                    "Begin Node": ["X 1"],
                    "End Node": ["HH 2"],
                    "Has Path": [false],
                    "Comment": "Target Sensor can NOT sense or identify targets"
                }
            },
        {
                "NOT POSSIBLE 5": {
                    "Begin Node": ["X 2"],
                    "End Node": ["HH 1"],
                    "Has Path": [false],
                    "Comment": "Target Sensor can NOT sense or identify targets"
                }
            },
            {
                "Senses Targets ONLY": {
                    "Begin Node": ["X 3", "X 3", "X 2", "X 2", "X 2", "X 1", "HH 1"],
                    "End Node": ["CC 2", "DD 1", "KK 2", "LL 2","HH 1", "HH 1", "HH 2"],
```

```
                    "Has Path": [true, true, false, true, true, true, true],
                    "Comment": "Target Sensor senses but cannot identify targets as friend/foe"
                }
            }
        ],
  "Fire Ordnance from Weapon System 5.1": [
            {
                "Fire via Fiber Optic Cable and VHF Radio": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.2", "JJ 1.1"],
                    "End Node": ["DD 1", "QQ 5.1", "JJ 5.1.a", "JJ 5.1.b"],
                    "Has Path": [true, true, true, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic or Radio command"
                }
            },
            {
                "NOT POSSIBLE 1": {
                    "Begin Node": ["X 3"],
                    "End Node": ["DD 1"],
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
     {
                "NOT POSSIBLE 2": {
                    "Begin Node": ["X 1"],
                    "End Node": ["QQ 5.1"],
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
     {
                "NOT POSSIBLE 3": {
                    "Begin Node": ["JJ 1.1", "JJ 1.2"],
                    "End Node": ["JJ 5.1.b", "JJ 5.1.a"],
                    "Has Path": [false, false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
            {
                "Fire via Fiber Optic Cable ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.1", "JJ 5.1.b", "JJ 5.1.a"],
                    "Has Path": [true, true, false, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic command ONLY"
                }
            },
     {
                "Fire via Radio ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.1", "JJ 5.1.b", "JJ 5.1.a"],
                    "Has Path": [true, true, true, false],
                    "Comment": "Capable of firing ordnance via Radio command ONLY"
                }
            }

        ],
  "Fire Ordnance from Weapon System 5.2": [
```

```
            {
                "Fire via Fiber Optic Cable and VHF Radio": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.2", "JJ 1.1"],
                    "End Node": ["DD 1", "QQ 5.2", "JJ 5.2.a", "JJ 5.2.b"],
                    "Has Path": [true, true, true, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic or Radio command"
                }
            },
            {
                "NOT POSSIBLE 1": {
                    "Begin Node": ["X 3"],
                    "End Node": ["DD 1"],
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
    {
                "NOT POSSIBLE 2": {
                    "Begin Node": ["X 1"],
                    "End Node": ["QQ 5.2"],
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
    {
                "NOT POSSIBLE 3": {
                    "Begin Node": ["JJ 1.1", "JJ 1.2"],
                    "End Node": ["JJ 5.2.b", "JJ 5.2.a"],
                    "Has Path": [false, false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
            {
                "Fire via Fiber Optic Cable ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.2", "JJ 5.2.b", "JJ 5.2.a"],
                    "Has Path": [true, true, false, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic command ONLY"
                }
            },
    {
                "Fire via Radio ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.2", "JJ 5.2.b", "JJ 5.2.a"],
                    "Has Path": [true, true, true, false],
                    "Comment": "Capable of firing ordnance via Radio command ONLY"
                }
            }

        ],
  "Fire Ordnance from Weapon System 5.3": [
            {
                "Fire via Fiber Optic Cable and VHF Radio": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.2", "JJ 1.1"],
                    "End Node": ["DD 1", "QQ 5.3", "JJ 5.3.a", "JJ 5.3.b"],
                    "Has Path": [true, true, true, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic or Radio command"
```

```
                }
            },
            {
                "NOT POSSIBLE 1": {
                    "Begin Node": ["X 3"],
                    "End Node": ["DD 1"],
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
    {
                "NOT POSSIBLE 2": {
                    "Begin Node": ["X 1"],
                    "End Node": ["QQ 5.3"],
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
    {
                "NOT POSSIBLE 3": {
                    "Begin Node": ["JJ 1.1", "JJ 1.2"],
                    "End Node": ["JJ 5.3.b", "JJ 5.3.a"],
                    "Has Path": [false, false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
            {
                "Fire via Fiber Optic Cable ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.3", "JJ 5.3.b", "JJ 5.3.a"],
                    "Has Path": [true, true, false, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic command ONLY"
                }
            },
    {
                "Fire via Radio ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.3", "JJ 5.3.b", "JJ 5.3.a"],
                    "Has Path": [true, true, true, false],
                    "Comment": "Capable of firing ordnance via Radio command ONLY"
                }
            }

        ],
  "Fire Ordnance from Weapon System 5.4": [
            {
                "Fire via Fiber Optic Cable and VHF Radio": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.2", "JJ 1.1"],
                    "End Node": ["DD 1", "QQ 5.4", "JJ 5.4.a", "JJ 5.4.b"],
                    "Has Path": [true, true, true, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic or Radio command"
                }
            },
            {
                "NOT POSSIBLE 1": {
                    "Begin Node": ["X 3"],
                    "End Node": ["DD 1"],
```

```
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
        {
                "NOT POSSIBLE 2": {
                    "Begin Node": ["X 1"],
                    "End Node": ["QQ 5.4"],
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
        {
                "NOT POSSIBLE 3": {
                    "Begin Node": ["JJ 1.1", "JJ 1.2"],
                    "End Node": ["JJ 5.4.b", "JJ 5.4.a"],
                    "Has Path": [false, false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
            {
                "Fire via Fiber Optic Cable ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.4", "JJ 5.4.b", "JJ 5.4.a"],
                    "Has Path": [true, true, false, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic command ONLY"
                }
            },
        {
                "Fire via Radio ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.4", "JJ 5.4.b", "JJ 5.4.a"],
                    "Has Path": [true, true, true, false],
                    "Comment": "Capable of firing ordnance via Radio command ONLY"
                }
            }

        ],
  "Fire Ordnance from Weapon System 5.5": [
            {
                "Fire via Fiber Optic Cable and VHF Radio": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.2", "JJ 1.1"],
                    "End Node": ["DD 1", "QQ 5.5", "JJ 5.5.a", "JJ 5.5.b"],
                    "Has Path": [true, true, true, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic or Radio command"
                }
            },
            {
                "NOT POSSIBLE 1": {
                    "Begin Node": ["X 3"],
                    "End Node": ["DD 1"],
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
        {
                "NOT POSSIBLE 2": {
```

```
                    "Begin Node": ["X 1"],
                    "End Node": ["QQ 5.5"],
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
    {
                "NOT POSSIBLE 3": {
                    "Begin Node": ["JJ 1.1", "JJ 1.2"],
                    "End Node": ["JJ 5.5.b", "JJ 5.5.a"],
                    "Has Path": [false, false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
            {
                "Fire via Fiber Optic Cable ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.5", "JJ 5.5.b", "JJ 5.5.a"],
                    "Has Path": [true, true, false, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic command ONLY"
                }
            },
    {
                "Fire via Radio ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.5", "JJ 5.5.b", "JJ 5.5.a"],
                    "Has Path": [true, true, true, false],
                    "Comment": "Capable of firing ordnance via Radio command ONLY"
                }
            }

        ],
  "Fire Ordnance from Weapon System 5.6": [
            {
                "Fire via Fiber Optic Cable and VHF Radio": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.2", "JJ 1.1"],
                    "End Node": ["DD 1", "QQ 5.6", "JJ 5.6.a", "JJ 5.6.b"],
                    "Has Path": [true, true, true, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic or Radio command"
                }
            },
            {
                "NOT POSSIBLE 1": {
                    "Begin Node": ["X 3"],
                    "End Node": ["DD 1"],
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
    {
                "NOT POSSIBLE 2": {
                    "Begin Node": ["X 1"],
                    "End Node": ["QQ 5.6"],
                    "Has Path": [false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
```

```
    {
                "NOT POSSIBLE 3": {
                    "Begin Node": ["JJ 1.1", "JJ 1.2"],
                    "End Node": ["JJ 5.6.b", "JJ 5.6.a"],
                    "Has Path": [false, false],
                    "Comment": "Can NOT fire ordnance"
                }
            },
            {
                "Fire via Fiber Optic Cable ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.6", "JJ 5.6.b", "JJ 5.6.a"],
                    "Has Path": [true, true, false, true],
                    "Comment": "Capable of firing ordnance via Fiber Optic command ONLY"
                }
            },
    {
                "Fire via Radio ONLY": {
                    "Begin Node": ["X 3", "X 1", "JJ 1.1", "JJ 1.2"],
                    "End Node": ["DD 1", "QQ 5.6", "JJ 5.6.b", "JJ 5.6.a"],
                    "Has Path": [true, true, true, false],
                    "Comment": "Capable of firing ordnance via Radio command ONLY"
                }
            }

        ]
    },
    "SOS Structure": {
        "Admin Nodes": [],
        "Terminal Nodes": ["X", "XX"],
        "Edges": {
            "X": ["X 3"],
            "XX 5.1": ["XX"],
            "XX 5.2": ["XX"],
            "XX 5.3": ["XX"],
            "XX 5.4": ["XX"],
            "XX 5.5": ["XX"],
            "XX 5.6": ["XX"]
        },
        "Capability Edges": {
            "DD 3": ["X 1"],
            "CC 3": ["X 2"],
            "EE 1": ["BB 3"],
            "EE 1.1": ["BB 3"],
      "HH 1":["X 2"],
            "HH 2": ["EE 1.1"],
      "KK 2": ["EE 1.1"],
      "LL 2": ["EE 1.1"],
            "JJ 1.b": ["X 5.1","X 5.2","X 5.3","X 5.4","X 5.5","X 5.6"],
            "JJ 1.1.a": ["X 5.1"],
            "JJ 1.2.a": ["X 5.2"],
            "JJ 1.3.a": ["X 5.3"],
            "JJ 1.4.a": ["X 5.4"],
            "JJ 1.5.a": ["X 5.5"],
            "JJ 1.6.a": ["X 5.6"]
        }
    },
```

```
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",

    "Maintainer": null,
    "Maintainer Title": null,
    "Maintainer Organization": null
}
```

F.3.2 System Data Files

Listing F.2: The command and control system data file for the Reference system of systems (Command_and_Control.sdf.json)


```
{
    "HEADER COMMENTS": "The C2 system for the Reference SOS",
    "System": {
        "Command & Control": {
            "ID": "System 1",
            "type": "equipment",
            "subtype": "mechanical",
      "color":"#0070C1",
            "VNTK": null,
            "thresholds": {
                "static overpressure": 26.797956022081607,
                "dynamic pressure": 6.699489005520402,
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            }
        }
    },
    "Subsystems": {
        "Personnel & Equipment Shelter": {
            "ID": "Personnel and Equipment Shelter",
            "type": "equipment",
            "subtype": "mechanical",
            "relative position": [
                0,
                -0.8384,
                2.5
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 17.235124224347977,
                "dynamic pressure": 4.308781056086994,
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            },
            "Components": {
                "Soldier 1": {
                    "ID": null,
                    "type": "human",
                    "subtype": "personnel",
                    "relative position": [
```

```
                        0.92702,
                        0.7054,
                        2.25596
                    ],
                    "VNTK": "50I4",
                    "thresholds": {
                        "static overpressure": 36.98445717315175,
                        "dynamic pressure": "inf",
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": 4438.13486077821,
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": 0.5
                    }
                },
                "Soldier 2": {
                    "ID": null,
                    "type": "human",
                    "subtype": "personnel",
                    "relative position": [
                        -0.92702,
                        0.70533,
                        2.25678
                    ],
                    "VNTK": "50I4",
                    "thresholds": {
                        "static overpressure": 17.361674221893555,
                        "dynamic pressure": "inf",
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": 2083.4009066272265,
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": 0.5
                    }
                },
                "Soldier 3": {
                    "ID": null,
                    "type": "human",
                    "subtype": "personnel",
                    "relative position": [
                        0,
                        0.705,
                        2.256
                    ],
                    "VNTK": "50I4",
                    "thresholds": {
                        "static overpressure": 32.01190108028209,
                        "dynamic pressure": "inf",
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": 3841.428129633851,
```

```
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": 0.5
                    }
                },
                "Power Plant Controller": {
                    "ID": "Mobile Power Plant controller",
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0,
                        1.25,
                        2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 9.102935471559185,
                        "dynamic pressure": 1.3004193530798835,
                        "windspeed": "inf",
                        "thermal fluence": 260.0838706159767,
                        "total dose": 1300419.3530798836,
                        "neutron dose": "inf",
                        "neutron fluence": 1300419353079.8835,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 13004193530.798836,
                        "PD": "inf"
                    }
                }
            }
        },
        "Operations Subsystem": {
            "ID": "Operation subsystem",
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                0,
                1.7,
                2.5
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 6.828929167721264,
                "dynamic pressure": 0.9755613096744663,
                "windspeed": "inf",
                "thermal fluence": 195.11226193489327,
                "total dose": 975561.3096744663,
                "neutron dose": "inf",
                "neutron fluence": 975561309674.4663,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 9755613096.744663,
                "PD": "inf"
            },
            "Components": {
                "Operator Station 1": {
                    "ID": null,
```

```
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.927,
                        1.6,
                        2.36
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.575515556424029,
                        "dynamic pressure": 0.9393593652034327,
                        "windspeed": "inf",
                        "thermal fluence": 187.87187304068652,
                        "total dose": 939359.3652034326,
                        "neutron dose": "inf",
                        "neutron fluence": 939359365203.4326,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9393593652.034327,
                        "PD": "inf"
                    }
                },
                "Operator Station 2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -0.927,
                        1.6,
                        2.36
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.576993729766205,
                        "dynamic pressure": 1.0824276756808864,
                        "windspeed": "inf",
                        "thermal fluence": 216.48553513617728,
                        "total dose": 1082427.6756808865,
                        "neutron dose": "inf",
                        "neutron fluence": 1082427675680.8864,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10824276756.808865,
                        "PD": "inf"
                    }
                },
                "Target Sensor Computer 1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1,
                        -3,
                        2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.70595904717695,
                        "dynamic pressure": 1.10085129245385,
```

```
                        "windspeed": "inf",
                        "thermal fluence": 220.17025849077,
                        "total dose": 1100851.2924538502,
                        "neutron dose": "inf",
                        "neutron fluence": 1100851292453.85,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11008512924.5385,
                        "PD": "inf"
                    }
                },
                "Data Cable 1.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "fiber optics",
                    "relative position": [
                        2,
                        9,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 17.720899019591062,
                        "dynamic pressure": 4.430224754897766,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": 886.0449509795532,
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Weapon Control Computer": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.92985,
                        -1.9864,
                        2.75
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.206620271378911,
                        "dynamic pressure": 1.1723743244827016,
                        "windspeed": "inf",
                        "thermal fluence": 234.47486489654034,
                        "total dose": 1172374.3244827017,
                        "neutron dose": "inf",
                        "neutron fluence": 1172374324482.7017,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11723743244.827017,
                        "PD": "inf"
                    }
                },
                "VHF Antenna 1": {
```

```
                    "ID": null,
                    "type": "equipment",
                    "subtype": "antenna",
                    "relative position": [
                        1.5,
                        -2.44,
                        5.42
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 10.779814737779464,
                        "dynamic pressure": 1.539973533968495,
                        "windspeed": 30.7994706793699,
                        "thermal fluence": 307.994706793699,
                        "total dose": 1539973.533968495,
                        "neutron dose": "inf",
                        "neutron fluence": 1539973533968.495,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 15399735339.68495,
                        "PD": "inf"
                    }
                },
                "Fiber Optic Modem 1": {
                    "ID": "Fiber optic modem 1",
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1,
                        -2.8,
                        2.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.6704639430946795,
                        "dynamic pressure": 1.09578056329924,
                        "windspeed": "inf",
                        "thermal fluence": 219.156112659848,
                        "total dose": 1095780.5632992398,
                        "neutron dose": "inf",
                        "neutron fluence": 1095780563299.2399,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10957805632.9924,
                        "PD": "inf"
                    }
                },
                "Optical Fiber 1.1": {
                    "ID": "Optical fiber 1.1",
                    "type": "equipment",
                    "subtype": "fiber optics",
                    "relative position": [
                        -295,
                        412,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 14.480577501545934,
```

```
                        "dynamic pressure": 3.6201443753864835,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": 724.0288750772968,
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Optical Fiber 1.2": {
                    "ID": "Optical fiber 1.2",
                    "type": "equipment",
                    "subtype": "fiber optics",
                    "relative position": [
                        -175,
                        301,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 18.30149020391326,
                        "dynamic pressure": 4.575372550978315,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": 915.074510195663,
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Optical Fiber 1.3": {
                    "ID": "Optical fiber 1.3",
                    "type": "equipment",
                    "subtype": "fiber optics",
                    "relative position": [
                        -55.0,
                        412,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 25.408385377889743,
                        "dynamic pressure": 6.352096344472436,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": 1270.419268894487,
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
```

```
                "Optical Fiber 1.4": {
                    "ID": "Optical fiber 1.4",
                    "type": "equipment",
                    "subtype": "fiber optics",
                    "relative position": [
                        65.8,
                        411.9,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 18.29430960122744,
                        "dynamic pressure": 4.57357740030686,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": 914.7154800613721,
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Optical Fiber 1.5": {
                    "ID": "Optical fiber 1.5",
                    "type": "equipment",
                    "subtype": "fiber optics",
                    "relative position": [
                        185.2,
                        291.9,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 18.543269919427416,
                        "dynamic pressure": 4.635817479856854,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": 927.1634959713708,
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Optical Fiber 1.6": {
                    "ID": "Optical fiber 1.6",
                    "type": "equipment",
                    "subtype": "fiber optics",
                    "relative position": [
                        304.9,
                        421.1,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
```

```
                        "static overpressure": 8.441249410538909,
                        "dynamic pressure": 2.110312352634727,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": 422.06247052694545,
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                }
            }
        }
    },
    "capabilities": {
        "Protect Personnel and Eqipment": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 1"
                    ],
                    "End Node": [
                        "FF 1"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Protects Personnel and Eqipment"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 1"
                    ],
                    "End Node": [
                        "FF 1"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Does NOT protect personnel and eqipment"
                }
            }
        ],
        "Control Mobile Power Plant Remotely": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 1"
                    ],
                    "End Node": [
                        "EE 1"
                    ],
                    "Has Path": [
                        true
```

```
                    ],
                    "Comment": "Remote control of Mobile Power Plant possible"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 1"
                    ],
                    "End Node": [
                        "EE 1"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Remote control of Mobile Power Plant NOT possible"
                }
            }
        ],
        "Control Target Sensor Remotely": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 1"
                    ],
                    "End Node": [
                        "HH 1"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Remote control of Target Sensor possible"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 1"
                    ],
                    "End Node": [
                        "HH 1"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Remote control of Target Sensor NOT possible"
                }
            }
        ],
        "Control Weapon System 1": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
```

```
                        "JJ 1.1.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Can control Weapon System 1 by cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.1.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        false
                    ],
                    "Comment": "Can NOT control Weapon Station 1"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.1.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can control Weapon System 1 by cable ONLY"
                }
            },
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.1.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        true
```

```
                    ],
                    "Comment": "Can control Weapon System 1 by radio ONLY"
                }
            }
        ],
        "Control Weapon System 2": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.2.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Can control Weapon System 1 by cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.2.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        false
                    ],
                    "Comment": "Can NOT control Weapon Station 1"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.2.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can control Weapon System 1 by cable ONLY"
                }
            },
```

```
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.2.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Can control Weapon System 1 by radio ONLY"
                }
            }
        ],
        "Control Weapon System 3": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.3.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Can control Weapon System 1 by cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.3.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        false
                    ],
                    "Comment": "Can NOT control Weapon Station 1"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 1",
```

```
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.3.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can control Weapon System 1 by cable ONLY"
                }
            },
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.3.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Can control Weapon System 1 by radio ONLY"
                }
            }
        ],
        "Control Weapon System 4": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.4.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Can control Weapon System 1 by cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.4.a",
```

```
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        false
                    ],
                    "Comment": "Can NOT control Weapon Station 1"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.4.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can control Weapon System 1 by cable ONLY"
                }
            },
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.4.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Can control Weapon System 1 by radio ONLY"
                }
            }
        ],
        "Control Weapon System 5": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.5.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
```

```
                        true
                    ],
                    "Comment": "Can control Weapon System 1 by cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.5.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        false
                    ],
                    "Comment": "Can NOT control Weapon Station 1"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.5.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can control Weapon System 1 by cable ONLY"
                }
            },
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.5.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Can control Weapon System 1 by radio ONLY"
                }
            }
        ],
```

```
        "Control Weapon System 6": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.6.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Can control Weapon System 1 by cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.6.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        false
                    ],
                    "Comment": "Can NOT control Weapon Station 1"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
                    ],
                    "End Node": [
                        "JJ 1.6.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can control Weapon System 1 by cable ONLY"
                }
            },
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
                        "X 1",
                        "X 1"
```

```
                    ],
                    "End Node": [
                        "JJ 1.6.a",
                        "JJ 1.b"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Can control Weapon System 1 by radio ONLY"
                }
            }
        ]
    },
    "Structure": {
        "Admin Nodes": [
            "DD 1",
            "FF 1",
            "EE 1.1",
            "EE 1",
            "HH 1",
            "JJ 1.b",
            "JJ 1.1.a",
            "JJ 1.2.a",
            "JJ 1.3.a",
            "JJ 1.4.a",
            "JJ 1.5.a",
            "JJ 1.6.a",
            "JJ 1.a",
            "JJ 1",
            "JJ 1.1",
            "JJ 1.2"
        ],
        "Terminal Nodes": [
            "X 1",
            "XX 1"
        ],
        "Edges": {
            "X 1": [
                "Command & Control"
            ],
            "Command & Control": [
                "DD 1"
            ],
            "DD 1": [
                "Personnel & Equipment Shelter"
            ],
            "Personnel & Equipment Shelter": [
                "FF 1"
            ],
            "FF 1": [
                "Soldier 1",
                "Soldier 2",
                "Soldier 3"
            ],
            "Soldier 1": [
                "EE 1.1"
```

```
            ],
            "Soldier 2": [
                "EE 1.1"
            ],
            "Soldier 3": [
                "EE 1.1"
            ],
            "EE 1.1": [
                "Power Plant Controller",
                "Operations Subsystem"
            ],
            "Power Plant Controller": [
                "EE 1"
            ],
            "EE 1": [
                "XX 1"
            ],
            "Operations Subsystem": [
                "Operator Station 1",
                "Operator Station 2"
            ],
            "Operator Station 1": [
                "Target Sensor Computer 1"
            ],
            "Operator Station 2": [
                "Target Sensor Computer 1"
            ],
            "Target Sensor Computer 1": [
                "Data Cable 1.1",
                "Weapon Control Computer"
            ],
            "Data Cable 1.1": [
                "HH 1"
            ],
            "HH 1": [
                "XX 1"
            ],
            "Weapon Control Computer": [
                "JJ 1.1",
                "JJ 1.2"
            ],
            "JJ 1.1": [
                "VHF Antenna 1"
            ],
            "JJ 1.2": [
                "Fiber Optic Modem 1"
            ],
            "VHF Antenna 1": [
                "JJ 1.b"
            ],
            "JJ 1.b": [
                "JJ 1"
            ],
            "JJ 1": [
                "XX 1"
            ],
            "Fiber Optic Modem 1": [
```

```
                "Optical Fiber 1.1",
                "Optical Fiber 1.2",
                "Optical Fiber 1.3",
                "Optical Fiber 1.4",
                "Optical Fiber 1.5",
                "Optical Fiber 1.6"
            ],
            "Optical Fiber 1.1": [
                "JJ 1.1.a"
            ],
            "Optical Fiber 1.2": [
                "JJ 1.2.a"
            ],
            "Optical Fiber 1.3": [
                "JJ 1.3.a"
            ],
            "Optical Fiber 1.4": [
                "JJ 1.4.a"
            ],
            "Optical Fiber 1.5": [
                "JJ 1.5.a"
            ],
            "Optical Fiber 1.6": [
                "JJ 1.6.a"
            ],
            "JJ 1.1.a": [
                "JJ 1.a"
            ],
            "JJ 1.2.a": [
                "JJ 1.a"
            ],
            "JJ 1.3.a": [
                "JJ 1.a"
            ],
            "JJ 1.4.a": [
                "JJ 1.a"
            ],
            "JJ 1.5.a": [
                "JJ 1.a"
            ],
            "JJ 1.6.a": [
                "JJ 1.a"
            ],
            "JJ 1.a": [
                "JJ 1"
            ]
        }
    },
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",
    "Maintainer": null,
    "Maintainer Title": null,
    "Maintainer Organization": null
}
```

Listing F.3: The target sensor system data file for the Reference system of systems (Target_Sensor.sdf.json)


```
{
    "HEADER COMMENTS": "The Target Sensor system for the Reference SOS",
    "System": {
        "Target Sensor": {
            "ID": "System 2",
            "type": "equipment",
            "subtype": "mechanical",
      "color":"#E17800",
            "VNTK": null,
            "thresholds": {
                "static overpressure": 15.068456183529497,
                "dynamic pressure": 3.767114045882374,
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            }
        }
    },
    "Subsystems": {
        "Equipment Shelter": {
            "ID": null,
            "type": "equipment",
            "subtype": "mechanical",
            "relative position": [
                0,
                -0.862,
                2.65
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 23.730736358805245,
                "dynamic pressure": 5.932684089701311,
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            }
        },
        "Target Sensor Computer 2": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                0.6,
                1.25,
                3
            ],
```

```
            "VNTK": null,
            "thresholds": {
                "static overpressure": 8.278807564171357,
                "dynamic pressure": 1.1826867948816224,
                "windspeed": "inf",
                "thermal fluence": 236.5373589763245,
                "total dose": 1182686.7948816225,
                "neutron dose": "inf",
                "neutron fluence": 1182686794881.6223,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 11826867948.816225,
                "PD": "inf"
            },
            "Components": {
                "Digital Processor": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.63,
                        0.5,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.435600116317092,
                        "dynamic pressure": 0.9193714451881561,
                        "windspeed": "inf",
                        "thermal fluence": 183.8742890376312,
                        "total dose": 919371.4451881561,
                        "neutron dose": "inf",
                        "neutron fluence": 919371445188.156,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9193714451.881561,
                        "PD": "inf"
                    }
                },
                "Signal Generator": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.63,
                        0.5,
                        2.0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.019720854464697,
                        "dynamic pressure": 0.7171029792092424,
                        "windspeed": "inf",
                        "thermal fluence": 143.42059584184847,
                        "total dose": 717102.9792092424,
                        "neutron dose": "inf",
                        "neutron fluence": 717102979209.2424,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7171029792.092423,
```

```
                        "PD": "inf"
                    }
                },
                "Transmitter Interface": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.5,
                        -1.25,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 9.092769432645156,
                        "dynamic pressure": 1.2989670618064508,
                        "windspeed": "inf",
                        "thermal fluence": 259.79341236129017,
                        "total dose": 1298967.0618064508,
                        "neutron dose": "inf",
                        "neutron fluence": 1298967061806.451,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12989670618.064508,
                        "PD": "inf"
                    }
                },
                "Signal Transmitter": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.5,
                        -1.5,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 10.068706051638491,
                        "dynamic pressure": 1.4383865788054988,
                        "windspeed": "inf",
                        "thermal fluence": 287.67731576109975,
                        "total dose": 1438386.5788054988,
                        "neutron dose": "inf",
                        "neutron fluence": 1438386578805.4988,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 14383865788.054989,
                        "PD": "inf"
                    }
                },
                "Signal Receiver": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -0.6,
                        -1,
                        3.2
```

```
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.947287280594054,
                        "dynamic pressure": 0.9924696115134363,
                        "windspeed": "inf",
                        "thermal fluence": 198.49392230268725,
                        "total dose": 992469.6115134363,
                        "neutron dose": "inf",
                        "neutron fluence": 992469611513.4363,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9924696115.134363,
                        "PD": "inf"
                    }
                },
                "Target Interrogator": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -0.6,
                        1.3,
                        2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.19778963692062,
                        "dynamic pressure": 1.1711128052743742,
                        "windspeed": "inf",
                        "thermal fluence": 234.22256105487486,
                        "total dose": 1171112.8052743743,
                        "neutron dose": "inf",
                        "neutron fluence": 1171112805274.3743,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11711128052.743742,
                        "PD": "inf"
                    }
                },
                "Interrogator Antenna": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "antenna",
                    "relative position": [
                        0,
                        2.16,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.383262233088093,
                        "dynamic pressure": 1.1976088904411561,
                        "windspeed": 23.952177808823123,
                        "thermal fluence": 239.52177808823123,
                        "total dose": 1197608.8904411562,
                        "neutron dose": "inf",
                        "neutron fluence": 1197608890441.1562,
                        "gamma ray dose": "inf",
```

```
                        "gamma ray dose rate": 11976088904.411562,
                        "PD": "inf"
                    }
                },
                "Guidance Correlator": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.6,
                        -2.5,
                        3
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 4.918857379156976,
                        "dynamic pressure": 0.7026939113081394,
                        "windspeed": "inf",
                        "thermal fluence": 140.5387822616279,
                        "total dose": 702693.9113081394,
                        "neutron dose": "inf",
                        "neutron fluence": 702693911308.1394,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7026939113.081394,
                        "PD": "inf"
                    }
                },
                "Guidance Processor": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.5,
                        -1.25,
                        3.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.211906402615608,
                        "dynamic pressure": 0.7445580575165155,
                        "windspeed": "inf",
                        "thermal fluence": 148.9116115033031,
                        "total dose": 744558.0575165155,
                        "neutron dose": "inf",
                        "neutron fluence": 744558057516.5155,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7445580575.165154,
                        "PD": "inf"
                    }
                },
                "Guidance Antenna": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "antenna",
                    "relative position": [
                        -0.835,
                        2.0,
```

```
                        3.6
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 4.612431507540696,
                        "dynamic pressure": 0.6589187867915279,
                        "windspeed": 13.178375735830558,
                        "thermal fluence": 131.7837573583056,
                        "total dose": 658918.7867915279,
                        "neutron dose": "inf",
                        "neutron fluence": 658918786791.528,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 6589187867.915279,
                        "PD": "inf"
                    }
                },
                "Target Detection Antenna": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "antenna",
                    "relative position": [
                        0,
                        1.5,
                        4.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.288603303487061,
                        "dynamic pressure": 0.8983719004981516,
                        "windspeed": 17.967438009963033,
                        "thermal fluence": 179.67438009963033,
                        "total dose": 898371.9004981517,
                        "neutron dose": "inf",
                        "neutron fluence": 898371900498.1516,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8983719004.981516,
                        "PD": "inf"
                    }
                }
            }
        }
    },
    "capabilities": {
        "Protect Equipment": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 2"
                    ],
                    "End Node": [
                        "CC 2"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Provides equipment ballistic and environmental protection"
                }
```

```
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 2"
                    ],
                    "End Node": [
                        "CC 2"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Does NOT provide equipment ballistic and environmental protection"
                }
            }
        ],
        "Communicate with C2": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 2"
                    ],
                    "End Node": [
                        "HH 2"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Receives and transmits data with C2"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 2"
                    ],
                    "End Node": [
                        "HH 2"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT receive and transmit dat with C2"
                }
            }
        ],
        "Detect Targets": [
            {
                "Detects and classifies targets": {
                    "Begin Node": [
                        "X 2",
                        "KK 2"
                    ],
                    "End Node": [
                        "KK 2",
                        "LL 2"
                    ],
```

```
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Detects and classifies targets as friend/foe"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 2",
                        "X 2"
                    ],
                    "End Node": [
                        "LL 2",
                        "KK 2"
                    ],
                    "Has Path": [
                        false,
                        false
                    ],
                    "Comment": "Can NOT detect or classify targets"
                }
            },
            {
                "Detects targets ONLY": {
                    "Begin Node": [
                        "X 2",
                        "X 2"
                    ],
                    "End Node": [
                        "KK 2",
                        "LL 2"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Detects but does not classify targets as friend/foe"
                }
            }
        ],
        "Guide Ordnance": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 2"
                    ],
                    "End Node": [
                        "MM 2"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Calculates and transmits guidance data to ordnance"
                }
            },
```

```
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 2"
                    ],
                    "End Node": [
                        "MM 2"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT communicate guidance data to ordnance"
                }
            }
        ]
    },
    "Structure": {
        "Admin Nodes": [
            "CC 2",
            "HH 2",
            "KK 2",
            "LL 2",
            "MM 2"
        ],
        "Terminal Nodes": [
            "X 2",
            "XX 2"
        ],
        "Edges": {
            "X 2": [
                "Target Sensor"
            ],
            "Target Sensor": [
                "Equipment Shelter"
            ],
            "Equipment Shelter": [
                "CC 2"
            ],
            "CC 2": [
                "Target Sensor Computer 2"
            ],
            "Target Sensor Computer 2": [
                "Digital Processor"
            ],
            "Digital Processor": [
                "HH 2"
            ],
            "HH 2": [
                "Signal Generator"
            ],
            "Signal Generator": [
                "Transmitter Interface"
            ],
            "Transmitter Interface": [
                "Signal Transmitter"
            ],
            "Signal Transmitter": [
```

```
                "Signal Receiver"
            ],
            "Signal Receiver": [
                "Target Interrogator",
                "Guidance Correlator",
                "Target Detection Antenna"
            ],
            "Target Interrogator": [
                "Interrogator Antenna"
            ],
            "Interrogator Antenna": [
                "KK 2"
            ],
            "KK 2": [
                "XX 2"
            ],
            "Guidance Correlator": [
                "Guidance Processor"
            ],
            "Guidance Processor": [
                "Guidance Antenna"
            ],
            "Guidance Antenna": [
                "MM 2"
            ],
            "MM 2": [
                "XX 2"
            ],
            "Target Detection Antenna": [
                "LL 2"
            ],
            "LL 2": [
                "XX 2"
            ]
        }
    },
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",
    "Maintainer": null,
    "Maintainer Title": null,
    "Maintainer Organization": null
}
```

Listing F.4: The electric power plant system data file for the Reference system of systems (Electric_Power_Plant.sdf.json)


```
{
    "HEADER COMMENTS": "The Electric Power Plant system for the Reference SOS",
    "System": {
        "Electric Power Plant": {
            "ID": "System 3",
            "type": "equipment",
            "subtype": "mechanical",
      "color":"#EB0F1E",
            "VNTK": null,
            "thresholds": {
                "static overpressure": 16.373506520354113,
                "dynamic pressure": 4.093376630088528,
                "windspeed": "inf",
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            }
        }
    },
    "Subsystems": {
        "Generator Set 3.1": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                0.133,
                -0.573,
                2.585
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 5.892514438428345,
                "dynamic pressure": 0.8417877769183351,
                "windspeed": "inf",
                "thermal fluence": 168.357555383667,
                "total dose": 841787.7769183351,
                "neutron dose": "inf",
                "neutron fluence": 841787776918.3351,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 8417877769.183351,
                "PD": "inf"
            },
            "Components": {
                "Air Intake 3.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0.2,
                        -0.9,
                        2.75
```

```
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 16.856076501862162,
                        "dynamic pressure": 4.214019125465541,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Fuel System 3.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0.4,
                        -1.5,
                        2.33
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 18.945985981980144,
                        "dynamic pressure": 4.736496495495036,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Engine 3.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0.133,
                        0.387,
                        2.585
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 21.647801564789255,
                        "dynamic pressure": 5.411950391197314,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
```

```
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Generator 3.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.133,
                        -1.533,
                        2.585
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.399475315497179,
                        "dynamic pressure": 0.9142107593567399,
                        "windspeed": "inf",
                        "thermal fluence": 182.842151871348,
                        "total dose": 914210.7593567399,
                        "neutron dose": "inf",
                        "neutron fluence": 914210759356.7399,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9142107593.567398,
                        "PD": "inf"
                    }
                }
            }
        },
        "Generator Set 3.2": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                0.133,
                -3.553,
                2.585
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 6.602712140036253,
                "dynamic pressure": 0.9432445914337505,
                "windspeed": "inf",
                "thermal fluence": 188.6489182867501,
                "total dose": 943244.5914337505,
                "neutron dose": "inf",
                "neutron fluence": 943244591433.7505,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 9432445914.337505,
                "PD": "inf"
            },
            "Components": {
                "Air Intake 3.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
```

```
                        0.2,
                        -3.88,
                        2.75
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 10.073355758828724,
                        "dynamic pressure": 2.518338939707181,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Fuel System 3.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0.4,
                        -1.5,
                        2.33
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 17.55765093047037,
                        "dynamic pressure": 4.3894127326175925,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Engine 3.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0.133,
                        -3.073,
                        2.585
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 14.914387352870872,
                        "dynamic pressure": 3.728596838217718,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
```

```
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Generator 3.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.133,
                        -4.513,
                        2.585
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 4.631073832823016,
                        "dynamic pressure": 0.6615819761175736,
                        "windspeed": "inf",
                        "thermal fluence": 132.31639522351472,
                        "total dose": 661581.9761175737,
                        "neutron dose": "inf",
                        "neutron fluence": 661581976117.5736,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 6615819761.175736,
                        "PD": "inf"
                    }
                }
            }
        },
        "Power Distribution Unit": {
            "ID": "PDU",
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                -1,
                -3.2935,
                1.957
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 6.285692411790552,
                "dynamic pressure": 0.8979560588272217,
                "windspeed": "inf",
                "thermal fluence": 179.59121176544434,
                "total dose": 897956.0588272217,
                "neutron dose": "inf",
                "neutron fluence": 897956058827.2217,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 8979560588.272217,
                "PD": "inf"
            },
            "Components": {
                "PDU Controller": {
                    "ID": null,
```

```
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -1.15,
                        -3.114,
                        2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.607547475168879,
                        "dynamic pressure": 0.8010782107384112,
                        "windspeed": "inf",
                        "thermal fluence": 160.21564214768225,
                        "total dose": 801078.2107384113,
                        "neutron dose": "inf",
                        "neutron fluence": 801078210738.4113,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8010782107.384112,
                        "PD": "inf"
                    }
                },
                "PDU Synchronizer": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -1,
                        -3.5,
                        2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.457654235567802,
                        "dynamic pressure": 0.7796648907954004,
                        "windspeed": "inf",
                        "thermal fluence": 155.93297815908008,
                        "total dose": 779664.8907954004,
                        "neutron dose": "inf",
                        "neutron fluence": 779664890795.4004,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7796648907.954003,
                        "PD": "inf"
                    }
                },
                "Cable J1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -5.45,
                        3.4,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 10.351443338067305,
                        "dynamic pressure": 2.5878608345168264,
```

```
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Cable J2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -5.5,
                        3.35,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 18.789923021712973,
                        "dynamic pressure": 4.697480755428243,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Cable J3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -5.55,
                        3.3,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 17.36218735613687,
                        "dynamic pressure": 4.340546839034218,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Cable J4": {
```

```
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -5.515,
                        -5.655,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 14.397489572561636,
                        "dynamic pressure": 3.599372393140409,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Cable J5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -5.52,
                        -5.66,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 15.59674239439444,
                        "dynamic pressure": 3.89918559859861,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                }
            }
        }
    },
    "capabilities": {
        "Generate Electrical Power": [
            {
                "Via Generator Set 1 and Generator Set 2": {
                    "Begin Node": [
                        "X 3",
                        "X 3"
                    ],
                    "End Node": [
```

```
                        "BB 3.1",
                        "BB 3.2"
                    ],
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Electrical power is generated by both generator sets"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 3"
                    ],
                    "End Node": [
                        "BB 3"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Electrical power generation NOT possible"
                }
            },
            {
                "Via Generator Set 1 or Generator Set 2": {
                    "Begin Node": [
                        "X 3"
                    ],
                    "End Node": [
                        "BB 3"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Electrical power is generated by both generator sets"
                }
            }
        ],
        "Power Prime Loads": [
            {
                "Powers C2 and Target Sensor": {
                    "Begin Node": [
                        "X 3",
                        "X 3"
                    ],
                    "End Node": [
                        "CC 3",
                        "DD 3"
                    ],
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Powers Command and Control and Target Sensor systems"
                }
            },
```

```
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 3",
                        "X 3"
                    ],
                    "End Node": [
                        "CC 3",
                        "DD 3"
                    ],
                    "Has Path": [
                        false,
                        false
                    ],
                    "Comment": "Can NOT power any prime loads"
                }
            },
            {
                "Powers C2 ONLY": {
                    "Begin Node": [
                        "X 3",
                        "X 3"
                    ],
                    "End Node": [
                        "CC 3",
                        "DD 3"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Powers Command and Control system ONLY"
                }
            },
            {
                "Powers Target Sensor ONLY": {
                    "Begin Node": [
                        "X 3",
                        "X 3"
                    ],
                    "End Node": [
                        "CC 3",
                        "DD 3"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Powers Target Sensor systems ONLY"
                }
            }
        ],
        "Communicate with C2": [
            {
                "Via Remote Control and Local Panel": {
                    "Begin Node": [
                        "X 3",
```

```
                        "X 3"
                    ],
                    "End Node": [
                        "EE 3.1",
                        "EE 3"
                    ],
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Communication with C2 possible via remote control and local control
    panel"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 3",
                        "X 3"
                    ],
                    "End Node": [
                        "EE 3.1",
                        "EE 3"
                    ],
                    "Has Path": [
                        false,
                        false
                    ],
                    "Comment": "Communication with C2 NOT possible"
                }
            },
            {
                "Via Local Panel ONLY": {
                    "Begin Node": [
                        "X 3",
                        "X 3"
                    ],
                    "End Node": [
                        "EE 3.1",
                        "EE 3"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Communication with C2 possible via local control panel only"
                }
            }
        ]
    },
    "Structure": {
        "Admin Nodes": [
            "AA 3",
            "BB 3.1",
            "BB 3.2",
            "BB 3",
            "CC 3",
```

```
            "DD 3",
            "EE 3.1",
            "EE 3"
        ],
        "Terminal Nodes": [
            "X 3",
            "XX 3"
        ],
        "Edges": {
            "X 3": [
                "Electric Power Plant"
            ],
            "Electric Power Plant": [
                "AA 3"
            ],
            "AA 3": [
                "Generator Set 3.1",
                "Generator Set 3.2"
            ],
            "Generator Set 3.1": [
                "Air Intake 3.1"
            ],
            "Air Intake 3.1": [
                "Fuel System 3.1"
            ],
            "Fuel System 3.1": [
                "Engine 3.1"
            ],
            "Engine 3.1": [
                "Generator 3.1"
            ],
            "Generator 3.1": [
                "BB 3.1"
            ],
            "BB 3.1": [
                "BB 3"
            ],
            "Generator Set 3.2": [
                "Air Intake 3.2"
            ],
            "Air Intake 3.2": [
                "Fuel System 3.2"
            ],
            "Fuel System 3.2": [
                "Engine 3.2"
            ],
            "Engine 3.2": [
                "Generator 3.2"
            ],
            "Generator 3.2": [
                "BB 3.2"
            ],
            "BB 3.2": [
                "BB 3"
            ],
            "BB 3": [
                "Power Distribution Unit"
```

```
            ],
            "Power Distribution Unit": [
                "PDU Controller"
            ],
            "PDU Controller": [
                "PDU Synchronizer",
                "EE 3.1"
            ],
            "PDU Synchronizer": [
                "Cable J1",
                "Cable J4"
            ],
            "Cable J1": [
                "Cable J2"
            ],
            "Cable J2": [
                "Cable J3"
            ],
            "Cable J3": [
                "CC 3"
            ],
            "Cable J4": [
                "DD 3"
            ],
            "EE 3.1": [
                "Cable J5"
            ],
            "Cable J5": [
                "EE 3"
            ],
            "CC 3": [
                "XX 3"
            ],
            "DD 3": [
                "XX 3"
            ],
            "EE 3": [
                "XX 3"
            ]
        }
    },
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",
    "Maintainer": null,
    "Maintainer Title": null,
    "Maintainer Organization": null
}
```

Listing F.5: The weapon system 1 system data file for the Reference system of systems (Weapon_System_1.sdf.json)


```
{
    "HEADER COMMENTS": "Weapon System 1 of the Reference SOS",
    "System": {
        "Weapon System 5.1": {
            "ID": "System 5.1",
            "type": "equipment",
            "subtype": "weapon",
      "color":"#00AA64",
            "VNTK": null,
            "thresholds": {
                "static overpressure": 24.47670923056489,
                "dynamic pressure": 12.238354615282445,
                "windspeed": 48.95341846112978,
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            }
        }
    },
    "Subsystems": {
        "15kW Generator Set 5.1": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                0,
                7.5,
                3.0
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 5.419037594338732,
                "dynamic pressure": 0.7741482277626761,
                "windspeed": "inf",
                "thermal fluence": 154.82964555253523,
                "total dose": 774148.2277626761,
                "neutron dose": "inf",
                "neutron fluence": 774148227762.6761,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 7741482277.626761,
                "PD": "inf"
            },
            "Components": {
                "Generator Air Intake 5.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -0.75,
                        7.25,
                        3.5
```

```
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 27.480936261622126,
                        "dynamic pressure": 6.870234065405532,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Generator Fuel System 5.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        7.5,
                        2.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 19.46989372343001,
                        "dynamic pressure": 4.867473430857502,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Diesel Engine 5.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        8.1,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 27.109869863730278,
                        "dynamic pressure": 6.7774674659325695,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
```

```
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Electric Generator 5.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0,
                        6.9,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 9.444406347099157,
                        "dynamic pressure": 1.3492009067284512,
                        "windspeed": "inf",
                        "thermal fluence": 269.8401813456902,
                        "total dose": 1349200.9067284511,
                        "neutron dose": "inf",
                        "neutron fluence": 1349200906728.4512,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 13492009067.284512,
                        "PD": "inf"
                    }
                }
            }
        },
        "Electronics System 5.1": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                -1.16,
                0.5,
                1.4
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 7.113304681354972,
                "dynamic pressure": 1.0161863830507103,
                "windspeed": "inf",
                "thermal fluence": 203.23727661014206,
                "total dose": 1016186.3830507103,
                "neutron dose": "inf",
                "neutron fluence": 1016186383050.7103,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 10161863830.507103,
                "PD": "inf"
            },
            "Components": {
                "AC Cabinet 5.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
```

```
                        -1.2,
                        0.5,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 11.293638386029944,
                        "dynamic pressure": 2.823409596507486,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Data Link Terminal 5.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.5,
                        1.4
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.7488286497785035,
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                        "windspeed": "inf",
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                        "dynamic pressure": 3.120747008936246,
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                    "subtype": "electrical",
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                    "VNTK": null,
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                        "neutron fluence": 935610396265.3839,
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                        "gamma ray dose rate": 13327099199.621668,
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                    }
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                    "subtype": "electrical",
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                        "gamma ray dose rate": 10388625888.48684,
                        "PD": "inf"
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                "Ordnance Relay Card 5.1.4": {
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                        "PD": "inf"
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                },
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                    "thresholds": {
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                        "windspeed": "inf",
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                        "neutron dose": "inf",
                        "neutron fluence": 960542589052.5112,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9605425890.525112,
                        "PD": "inf"
                    }
                },
                "Ordnance Relay Card 5.1.6": {
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                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
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                    "thresholds": {
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                        "dynamic pressure": 1.5896626863570875,
                        "windspeed": "inf",
                        "thermal fluence": 317.9325372714175,
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                        "gamma ray dose": "inf",
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                        "PD": "inf"
                    }
                },
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                    "subtype": "electrical",
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                    "thresholds": {
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                        "windspeed": "inf",
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                        "total dose": 990008.9523884612,
                        "neutron dose": "inf",
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                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9900089523.884611,
                        "PD": "inf"
                    }
                },
                "Ordnance Relay Card 5.1.8": {
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                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
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                    ],
                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 1.0137125077095972,
                        "windspeed": "inf",
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                        "PD": "inf"
                    }
                },
                "Ordnance Relay Card 5.1.9": {
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                    "subtype": "electrical",
                    "relative position": [
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                        "gamma ray dose": "inf",
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                        "PD": "inf"
                    }
                },
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                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
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                    ],
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                    "thresholds": {
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                        "neutron fluence": 1067794380547.0833,
                        "gamma ray dose": "inf",
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                        "PD": "inf"
                    }
                },
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                    "subtype": "electrical",
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                    "thresholds": {
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                        "dynamic pressure": 1.1942315583216239,
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                        "neutron fluence": 1194231558321.6238,
                        "gamma ray dose": "inf",
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                        "gamma ray dose rate": 11942315583.216238,
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                    "ID": null,
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                    "subtype": "electrical",
                    "relative position": [
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                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 1.1602229770759613,
                        "windspeed": "inf",
                        "thermal fluence": 232.04459541519228,
                        "total dose": 1160222.9770759614,
                        "neutron dose": "inf",
                        "neutron fluence": 1160222977075.9614,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11602229770.759613,
                        "PD": "inf"
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                "Canister 5.1.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0.345,
                        -2.05,
                        4.337
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                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 6.528578750216559,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
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                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Canister 5.1.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
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                        -2.05,
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                    "PD": "inf"
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            "Canister 5.1.3": {
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                "subtype": "mechanical",
                "relative position": [
                    0.933,
                    -2.435,
                    4.829
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                "VNTK": null,
                "thresholds": {
                    "static overpressure": 25.50738569458799,
                    "dynamic pressure": 6.376846423646998,
                    "windspeed": "inf",
                    "thermal fluence": "inf",
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            },
            "Canister 5.1.4": {
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                "subtype": "mechanical",
                "relative position": [
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                    "dynamic pressure": 3.161149888962489,
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```
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
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                "Canister 5.1.5": {
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                    "subtype": "mechanical",
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                        5.322
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                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 15.59002610524506,
                        "dynamic pressure": 3.897506526311265,
                        "windspeed": "inf",
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                        "gamma ray dose rate": "inf",
                        "PD": "inf"
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                "Canister 5.1.6": {
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                    "subtype": "mechanical",
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                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 4.566623577584972,
                        "windspeed": "inf",
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                        "PD": "inf"
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                "Canister 5.1.7": {
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```
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```

```
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                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
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                    "subtype": "mechanical",
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                        "windspeed": "inf",
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                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
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                        "PD": "inf"
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                        "windspeed": "inf",
                        "thermal fluence": 181.62358880347415,
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                        "neutron fluence": 908117944017.3707,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9081179440.173708,
                        "PD": "inf"
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                        "windspeed": "inf",
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                        "total dose": 828679.5819626856,
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```
                        "neutron dose": "inf",
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                        4.833
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                    "VNTK": null,
                    "thresholds": {
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                        "windspeed": "inf",
                        "thermal fluence": 198.74412895056543,
                        "total dose": 993720.6447528271,
                        "neutron dose": "inf",
                        "neutron fluence": 993720644752.8271,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9937206447.528273,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.1.4": {
                    "ID": null,
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                    "subtype": "ordnance",
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                        "thermal fluence": 256.21487785039324,
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                        "neutron dose": "inf",
                        "neutron fluence": 1281074389251.966,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12810743892.51966,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.1.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
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                    "relative position": [
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                        5.326
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                    "thresholds": {
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                        "dynamic pressure": 1.1429569141428964,
                        "windspeed": "inf",
                        "thermal fluence": 114.29569141428964,
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                        "neutron dose": "inf",
                        "neutron fluence": 571478457071.4481,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 5714784570.714481,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.1.6": {
                    "ID": null,
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                    "thresholds": {
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                        "neutron dose": "inf",
                        "neutron fluence": 908711758366.2227,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9087117583.662226,
                        "PD": "inf"
                    }
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                "Ordnance 5.1.7": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
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                        4.341
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                    "thresholds": {
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                        "dynamic pressure": 1.81050564463738,
                        "windspeed": "inf",
                        "thermal fluence": 181.050564463738,
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                        "total dose": 905252.82231869,
                        "neutron dose": "inf",
                        "neutron fluence": 905252822318.69,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9052528223.1869,
                        "PD": "inf"
                    }
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                "Ordnance 5.1.8": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
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                        4.341
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                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 2.1260999523282718,
                        "windspeed": "inf",
                        "thermal fluence": 212.60999523282717,
                        "total dose": 1063049.9761641358,
                        "neutron dose": "inf",
                        "neutron fluence": 1063049976164.1359,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10630499761.64136,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.1.9": {
                    "ID": null,
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                    "subtype": "ordnance",
                    "relative position": [
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                        4.833
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                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 2.4137292436068423,
                        "windspeed": "inf",
                        "thermal fluence": 241.37292436068424,
                        "total dose": 1206864.621803421,
                        "neutron dose": "inf",
                        "neutron fluence": 1206864621803.4211,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12068646218.034212,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.1.10": {
                    "ID": null,
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                    "thresholds": {
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                        "neutron dose": "inf",
                        "neutron fluence": 1232793899049.9248,
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                        "gamma ray dose rate": 12327938990.499249,
                        "PD": "inf"
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                "Ordnance 5.1.11": {
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                    "thresholds": {
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                        "dynamic pressure": 2.7818066486050386,
                        "windspeed": "inf",
                        "thermal fluence": 278.18066486050384,
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                        "neutron dose": "inf",
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                        "gamma ray dose rate": 13909033243.025192,
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                "Ordnance 5.1.12": {
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                    "thresholds": {
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                        "dynamic pressure": 2.8337443112698226,
                        "windspeed": "inf",
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                        "total dose": 1416872.1556349113,
                        "neutron dose": "inf",
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                        "PD": "inf"
                    }
                }
            }
        }
    },
    "capabilities": {
        "Power Self": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.1"
                    ],
                    "End Node": [
                        "OO 5.1"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Power available"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.1"
                    ],
                    "End Node": [
                        "OO 5.1"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Power NOT available"
                }
            }
        ],
        "Aims Self": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.1"
                    ],
                    "End Node": [
                        "PP 5.1"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Aims self"
                }
```

```
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.1"
                    ],
                    "End Node": [
                        "PP 5.1"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Does NOT aim self"
                }
            }
        ],
        "Fires Primary Weapon Ordnance": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.1"
                    ],
                    "End Node": [
                        "QQ 5.1"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Can fire one or more rounds of ordnance"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.1"
                    ],
                    "End Node": [
                        "QQ 5.1"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT fire primary weapon system"
                }
            }
        ],
        "Communicate with Command and Control System": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 5.1",
                        "X 5.1"
                    ],
                    "End Node": [
                        "JJ 5.1.a",
                        "JJ 5.1.b"
                    ],
```

```
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Communicates with C2 via cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.1"
                    ],
                    "End Node": [
                        "JJ 5.1"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT communicate with C2 system"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 5.1",
                        "X 5.1"
                    ],
                    "End Node": [
                        "JJ 5.1.a",
                        "JJ 5.1.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can communicate with C2 by cable ONLY"
                }
            },
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
                        "X 5.1",
                        "X 5.1"
                    ],
                    "End Node": [
                        "JJ 5.1.a",
                        "JJ 5.1.b"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Can communicate with C2 by radio ONLY"
                }
            }
        ]
    },
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    "Structure": {
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            "OO 5.1",
            "QQ 5.1",
            "JJ 5.1",
            "JJ 5.1.a",
            "JJ 5.1.b",
            "PP 5.1"
        ],
        "Terminal Nodes": [
            "X 5.1",
            "XX 5.1"
        ],
        "Edges": {
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                "Weapon System 5.1"
            ],
            "Weapon System 5.1": [
                "NN 5.1"
            ],
            "NN 5.1": [
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            ],
            "15kW Generator Set 5.1": [
                "Generator Air Intake 5.1"
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            "Generator Air Intake 5.1": [
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            "Electronics System 5.1": [
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                "Data Link Terminal 5.1"
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            "AC Cabinet 5.1": [
                "Heater Control 5.1",
                "Compass 5.1"
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                "Processor Card Cage 5.1"
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            "Processor Card Cage 5.1": [
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            "Compass 5.1": [
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                "Elevation Motor 5.1"
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            "Elevation Motor 5.1": [
                "PP 5.1"
            ],
            "PP 5.1": [
                "XX 5.1"
            ],
            "Data Link Terminal 5.1": [
                "Digital Processor 5.1"
            ],
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                "VHF Radio 5.1"
            ],
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            ],
            "JJ 5.1.a": [
                "JJ 5.1"
            ],
            "JJ 5.1": [
                "XX 5.1"
            ],
            "VHF Radio 5.1": [
                "EMP Suppressor 5.1"
            ],
            "EMP Suppressor 5.1": [
                "Radio Antenna 5.1"
            ],
            "Radio Antenna 5.1": [
                "JJ 5.1.b"
            ],
            "JJ 5.1.b": [
                "JJ 5.1"
            ],
```

```
            "Ordnance Interface Card 5.1": [
                "Fire Control 5.1"
            ],
            "Fire Control 5.1": [
                "Junction Box 5.1"
            ],
            "Junction Box 5.1": [
                "Data Cable 5.1.1",
                "Data Cable 5.1.2",
                "Data Cable 5.1.3"
            ],
            "Data Cable 5.1.1": [
                "Ordnance Relay Card 5.1.1",
                "Ordnance Relay Card 5.1.2",
                "Ordnance Relay Card 5.1.3",
                "Ordnance Relay Card 5.1.4"
            ],
            "Data Cable 5.1.2": [
                "Ordnance Relay Card 5.1.5",
                "Ordnance Relay Card 5.1.6",
                "Ordnance Relay Card 5.1.7",
                "Ordnance Relay Card 5.1.8"
            ],
            "Data Cable 5.1.3": [
                "Ordnance Relay Card 5.1.9",
                "Ordnance Relay Card 5.1.10",
                "Ordnance Relay Card 5.1.11",
                "Ordnance Relay Card 5.1.12"
            ],
            "Ordnance Relay Card 5.1.1": [
                "Canister 5.1.1"
            ],
            "Canister 5.1.1": [
                "Ordnance 5.1.1"
            ],
            "Ordnance 5.1.1": [
                "QQ 5.1"
            ],
            "Ordnance Relay Card 5.1.2": [
                "Canister 5.1.2"
            ],
            "Canister 5.1.2": [
                "Ordnance 5.1.2"
            ],
            "Ordnance 5.1.2": [
                "QQ 5.1"
            ],
            "Ordnance Relay Card 5.1.3": [
                "Canister 5.1.3"
            ],
            "Canister 5.1.3": [
                "Ordnance 5.1.3"
            ],
            "Ordnance 5.1.3": [
                "QQ 5.1"
            ],
            "Ordnance Relay Card 5.1.4": [
```

```
                "Canister 5.1.4"
            ],
            "Canister 5.1.4": [
                "Ordnance 5.1.4"
            ],
            "Ordnance 5.1.4": [
                "QQ 5.1"
            ],
            "Ordnance Relay Card 5.1.5": [
                "Canister 5.1.5"
            ],
            "Canister 5.1.5": [
                "Ordnance 5.1.5"
            ],
            "Ordnance 5.1.5": [
                "QQ 5.1"
            ],
            "Ordnance Relay Card 5.1.6": [
                "Canister 5.1.6"
            ],
            "Canister 5.1.6": [
                "Ordnance 5.1.6"
            ],
            "Ordnance 5.1.6": [
                "QQ 5.1"
            ],
            "Ordnance Relay Card 5.1.7": [
                "Canister 5.1.7"
            ],
            "Canister 5.1.7": [
                "Ordnance 5.1.7"
            ],
            "Ordnance 5.1.7": [
                "QQ 5.1"
            ],
            "Ordnance Relay Card 5.1.8": [
                "Canister 5.1.8"
            ],
            "Canister 5.1.8": [
                "Ordnance 5.1.8"
            ],
            "Ordnance 5.1.8": [
                "QQ 5.1"
            ],
            "Ordnance Relay Card 5.1.9": [
                "Canister 5.1.9"
            ],
            "Canister 5.1.9": [
                "Ordnance 5.1.9"
            ],
            "Ordnance 5.1.9": [
                "QQ 5.1"
            ],
            "Ordnance Relay Card 5.1.10": [
                "Canister 5.1.10"
            ],
            "Canister 5.1.10": [
```

```
                "Ordnance 5.1.10"
            ],
            "Ordnance 5.1.10": [
                "QQ 5.1"
            ],
            "Ordnance Relay Card 5.1.11": [
                "Canister 5.1.11"
            ],
            "Canister 5.1.11": [
                "Ordnance 5.1.11"
            ],
            "Ordnance 5.1.11": [
                "QQ 5.1"
            ],
            "Ordnance Relay Card 5.1.12": [
                "Canister 5.1.12"
            ],
            "Canister 5.1.12": [
                "Ordnance 5.1.12"
            ],
            "Ordnance 5.1.12": [
                "QQ 5.1"
            ],
            "QQ 5.1": [
                "XX 5.1"
            ]
        }
    },
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",
    "Maintainer": null,
    "Maintainer Title": null,
    "Maintainer Organization": null
}
```

Listing F.6: The weapon system 2 system data file for the Reference system of systems (Weapon_System_2.sdf.json)


```
{
    "HEADER COMMENTS": "Weapon System 2 of the Reference SOS",
    "System": {
        "Weapon System 5.2": {
            "ID": "System 5.2",
            "type": "equipment",
            "subtype": "weapon",
      "color":"#00AA64",
            "VNTK": null,
            "thresholds": {
                "static overpressure": 30.905715578501677,
                "dynamic pressure": 15.452857789250839,
                "windspeed": 61.811431157003355,
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            }
        }
    },
    "Subsystems": {
        "15kW Generator Set 5.2": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                0,
                7.5,
                3.0
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 8.131153038783378,
                "dynamic pressure": 1.1615932912547682,
                "windspeed": "inf",
                "thermal fluence": 232.31865825095363,
                "total dose": 1161593.2912547681,
                "neutron dose": "inf",
                "neutron fluence": 1161593291254.768,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 11615932912.547682,
                "PD": "inf"
            },
            "Components": {
                "Generator Air Intake 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -0.75,
                        7.25,
                        3.5
```

```
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 25.716989243764292,
                        "dynamic pressure": 6.429247310941073,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Generator Fuel System 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        7.5,
                        2.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 18.952770764212833,
                        "dynamic pressure": 4.738192691053208,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Diesel Engine 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        8.1,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 16.30424412124597,
                        "dynamic pressure": 4.076061030311492,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
```

```
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Electric Generator 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0,
                        6.9,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.932923494723609,
                        "dynamic pressure": 1.1332747849605156,
                        "windspeed": "inf",
                        "thermal fluence": 226.6549569921031,
                        "total dose": 1133274.7849605156,
                        "neutron dose": "inf",
                        "neutron fluence": 1133274784960.5156,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11332747849.605156,
                        "PD": "inf"
                    }
                }
            }
        },
        "Electronics System 5.2": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                -1.16,
                0.5,
                1.4
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 7.822754918777562,
                "dynamic pressure": 1.1175364169682231,
                "windspeed": "inf",
                "thermal fluence": 223.50728339364463,
                "total dose": 1117536.4169682232,
                "neutron dose": "inf",
                "neutron fluence": 1117536416968.2231,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 11175364169.682232,
                "PD": "inf"
            },
            "Components": {
                "AC Cabinet 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
```

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                        -1.2,
                        0.5,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 17.007962821142268,
                        "dynamic pressure": 4.251990705285567,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Data Link Terminal 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.5,
                        1.4
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.614878033630948,
                        "dynamic pressure": 1.0878397190901354,
                        "windspeed": "inf",
                        "thermal fluence": 217.5679438180271,
                        "total dose": 1087839.7190901355,
                        "neutron dose": "inf",
                        "neutron fluence": 1087839719090.1355,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10878397190.901354,
                        "PD": "inf"
                    }
                },
                "Digital Processor 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.25,
                        1.4
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.051268883962695,
                        "dynamic pressure": 0.7216098405660993,
                        "windspeed": "inf",
                        "thermal fluence": 144.32196811321987,
                        "total dose": 721609.8405660994,
```

```
                        "neutron dose": "inf",
                        "neutron fluence": 721609840566.0994,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7216098405.660994,
                        "PD": "inf"
                    }
                },
                "Fiber Optic Modem 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.75,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.07981836307632,
                        "dynamic pressure": 0.8685454804394742,
                        "windspeed": "inf",
                        "thermal fluence": 173.70909608789484,
                        "total dose": 868545.4804394742,
                        "neutron dose": "inf",
                        "neutron fluence": 868545480439.4742,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8685454804.394743,
                        "PD": "inf"
                    }
                },
                "VHF Radio 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.25,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 4.921237963118052,
                        "dynamic pressure": 0.7030339947311502,
                        "windspeed": "inf",
                        "thermal fluence": 140.60679894623004,
                        "total dose": 703033.9947311502,
                        "neutron dose": "inf",
                        "neutron fluence": 703033994731.1503,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7030339947.311502,
                        "PD": "inf"
                    }
                },
                "EMP Suppressor 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
```

```
                    "relative position": [
                        1,
                        0,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.923539866515719,
                        "dynamic pressure": 0.846219980930817,
                        "windspeed": "inf",
                        "thermal fluence": 169.2439961861634,
                        "total dose": 846219.980930817,
                        "neutron dose": "inf",
                        "neutron fluence": 846219980930.817,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8462199809.308169,
                        "PD": "inf"
                    }
                },
                "Radio Antenna 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "antenna",
                    "relative position": [
                        -1.5,
                        -2.5,
                        6.25
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.7449839084319505,
                        "dynamic pressure": 1.1064262726331358,
                        "windspeed": 22.128525452662714,
                        "thermal fluence": 221.28525452662714,
                        "total dose": 1106426.2726331358,
                        "neutron dose": "inf",
                        "neutron fluence": 1106426272633.1357,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11064262726.331358,
                        "PD": "inf"
                    }
                },
                "Compass 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
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                        -2.4,
                        2.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.378913105241407,
                        "dynamic pressure": 1.1969875864630581,
                        "windspeed": "inf",
                        "thermal fluence": 239.39751729261164,
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```
                        "total dose": 1196987.5864630581,
                        "neutron dose": "inf",
                        "neutron fluence": 1196987586463.058,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11969875864.63058,
                        "PD": "inf"
                    }
                },
                "GPS Receiver 5.2": {
                    "ID": "DAGR",
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -1.5,
                        -2.9,
                        2.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.821022518521498,
                        "dynamic pressure": 0.8315746455030711,
                        "windspeed": "inf",
                        "thermal fluence": 166.31492910061422,
                        "total dose": 831574.6455030711,
                        "neutron dose": "inf",
                        "neutron fluence": 831574645503.0712,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8315746455.030711,
                        "PD": "inf"
                    }
                },
                "GPS Antenna 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "antenna",
                    "relative position": [
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                        -2.5,
                        7.7
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.654134813163103,
                        "dynamic pressure": 0.950590687594729,
                        "windspeed": 19.01181375189458,
                        "thermal fluence": 190.1181375189458,
                        "total dose": 950590.687594729,
                        "neutron dose": "inf",
                        "neutron fluence": 950590687594.729,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9505906875.94729,
                        "PD": "inf"
                    }
                },
                "Power Controls 5.2": {
                    "ID": null,
                    "type": "equipment",
```

```
                    "subtype": "electrical",
                    "relative position": [
                        -1,
                        0,
                        1.25
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.799253786702206,
                        "dynamic pressure": 1.2570362552431722,
                        "windspeed": "inf",
                        "thermal fluence": 251.40725104863444,
                        "total dose": 1257036.2552431722,
                        "neutron dose": "inf",
                        "neutron fluence": 1257036255243.172,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12570362552.431723,
                        "PD": "inf"
                    }
                },
                "Motor Controls 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -1,
                        0.5,
                        1.25
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.15452472911171,
                        "dynamic pressure": 1.0220749613016729,
                        "windspeed": "inf",
                        "thermal fluence": 204.41499226033457,
                        "total dose": 1022074.9613016729,
                        "neutron dose": "inf",
                        "neutron fluence": 1022074961301.6729,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10220749613.01673,
                        "PD": "inf"
                    }
                },
                "Traverse & Elevation Mechanisms 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        -2.65,
                        2.22
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 14.718816073884685,
                        "dynamic pressure": 3.6797040184711713,
                        "windspeed": "inf",
```

```
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Azimuth Motor 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0,
                        -3.5,
                        2.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 11.140431021099992,
                        "dynamic pressure": 1.5914901458714275,
                        "windspeed": "inf",
                        "thermal fluence": 318.2980291742855,
                        "total dose": 1591490.1458714274,
                        "neutron dose": "inf",
                        "neutron fluence": 1591490145871.4275,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 15914901458.714275,
                        "PD": "inf"
                    }
                },
                "Elevation Motor 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0,
                        -2.5,
                        2.75
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 9.313836691814553,
                        "dynamic pressure": 1.3305480988306504,
                        "windspeed": "inf",
                        "thermal fluence": 266.1096197661301,
                        "total dose": 1330548.0988306503,
                        "neutron dose": "inf",
                        "neutron fluence": 1330548098830.6504,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 13305480988.306503,
                        "PD": "inf"
                    }
                },
                "Heater Control 5.2": {
                    "ID": null,
```

```
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1,
                        -0.6,
                        1.25
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.92029828784634,
                        "dynamic pressure": 0.9886140411209058,
                        "windspeed": "inf",
                        "thermal fluence": 197.72280822418116,
                        "total dose": 988614.0411209058,
                        "neutron dose": "inf",
                        "neutron fluence": 988614041120.9058,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9886140411.209059,
                        "PD": "inf"
                    }
                },
                "Processor Card Cage 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -1.2,
                        0.75,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.621992332699842,
                        "dynamic pressure": 1.2317131903856917,
                        "windspeed": "inf",
                        "thermal fluence": 246.34263807713833,
                        "total dose": 1231713.1903856918,
                        "neutron dose": "inf",
                        "neutron fluence": 1231713190385.6917,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12317131903.856916,
                        "PD": "inf"
                    }
                },
                "Ordnance Executive Processor Card 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.5,
                        -3.8,
                        2.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 3.7303737801769836,
                        "dynamic pressure": 0.5329105400252834,
```

```
                        "windspeed": "inf",
                        "thermal fluence": 106.58210800505668,
                        "total dose": 532910.5400252833,
                        "neutron dose": "inf",
                        "neutron fluence": 532910540025.2834,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 5329105400.252833,
                        "PD": "inf"
                    }
                },
                "Ordnance Interface Card 5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.48,
                        -3.8,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.46777300802372,
                        "dynamic pressure": 1.2096818582891027,
                        "windspeed": "inf",
                        "thermal fluence": 241.93637165782053,
                        "total dose": 1209681.8582891028,
                        "neutron dose": "inf",
                        "neutron fluence": 1209681858289.1028,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12096818582.891027,
                        "PD": "inf"
                    }
                }
            }
        },
        "Fire Control 5.2": {
            "ID": "Ordanance fire controls",
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                -1.16,
                0.3,
                1.42
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 4.38316049995642,
                "dynamic pressure": 0.62616578570806,
                "windspeed": "inf",
                "thermal fluence": 125.23315714161201,
                "total dose": 626165.78570806,
                "neutron dose": "inf",
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                },
                "Ordnance 5.2.7": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.93,
                        -2.053,
                        4.341
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 9.863360066148676,
                        "dynamic pressure": 2.818102876042479,
                        "windspeed": "inf",
                        "thermal fluence": 281.8102876042479,
```

```
                        "total dose": 1409051.4380212396,
                        "neutron dose": "inf",
                        "neutron fluence": 1409051438021.2395,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 14090514380.212395,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.2.8": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.343,
                        -2.053,
                        4.341
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.4525117170425705,
                        "dynamic pressure": 2.129289062012163,
                        "windspeed": "inf",
                        "thermal fluence": 212.9289062012163,
                        "total dose": 1064644.5310060815,
                        "neutron dose": "inf",
                        "neutron fluence": 1064644531006.0814,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10646445310.060814,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.2.9": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.93,
                        -2.438,
                        4.833
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.441138303949688,
                        "dynamic pressure": 2.1260395154141967,
                        "windspeed": "inf",
                        "thermal fluence": 212.60395154141966,
                        "total dose": 1063019.7577070983,
                        "neutron dose": "inf",
                        "neutron fluence": 1063019757707.0984,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10630197577.070984,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.2.10": {
                    "ID": null,
                    "type": "equipment",
```

```
                    "subtype": "ordnance",
                    "relative position": [
                        -0.343,
                        -2.438,
                        4.833
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.126850524475146,
                        "dynamic pressure": 2.036243006992899,
                        "windspeed": "inf",
                        "thermal fluence": 203.6243006992899,
                        "total dose": 1018121.5034964494,
                        "neutron dose": "inf",
                        "neutron fluence": 1018121503496.4495,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10181215034.964495,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.2.11": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.93,
                        -2.823,
                        5.326
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.13516483421457,
                        "dynamic pressure": 2.3243328097755915,
                        "windspeed": "inf",
                        "thermal fluence": 232.43328097755915,
                        "total dose": 1162166.4048877957,
                        "neutron dose": "inf",
                        "neutron fluence": 1162166404887.7957,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11621664048.877958,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.2.12": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.343,
                        -2.823,
                        5.326
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.135652959551388,
                        "dynamic pressure": 2.038757988443254,
                        "windspeed": "inf",
```

```
                        "thermal fluence": 203.87579884432537,
                        "total dose": 1019378.9942216269,
                        "neutron dose": "inf",
                        "neutron fluence": 1019378994221.627,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10193789942.216269,
                        "PD": "inf"
                    }
                }
            }
        }
    },
    "capabilities": {
        "Power Self": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.2"
                    ],
                    "End Node": [
                        "OO 5.2"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Power available"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.2"
                    ],
                    "End Node": [
                        "OO 5.2"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Power NOT available"
                }
            }
        ],
        "Aims Self": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.2"
                    ],
                    "End Node": [
                        "PP 5.2"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Aims self"
                }
```

```
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.2"
                    ],
                    "End Node": [
                        "PP 5.2"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Does NOT aim self"
                }
            }
        ],
        "Fires Primary Weapon Ordnance": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.2"
                    ],
                    "End Node": [
                        "QQ 5.2"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Can fire one or more rounds of ordnance"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.2"
                    ],
                    "End Node": [
                        "QQ 5.2"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT fire primary weapon system"
                }
            }
        ],
        "Communicate with Command and Control System": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 5.2",
                        "X 5.2"
                    ],
                    "End Node": [
                        "JJ 5.2.a",
                        "JJ 5.2.b"
                    ],
```

```
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Communicates with C2 via cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.2"
                    ],
                    "End Node": [
                        "JJ 5.2"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT communicate with C2 system"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 5.2",
                        "X 5.2"
                    ],
                    "End Node": [
                        "JJ 5.2.a",
                        "JJ 5.2.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can communicate with C2 by cable ONLY"
                }
            },
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
                        "X 5.2",
                        "X 5.2"
                    ],
                    "End Node": [
                        "JJ 5.2.a",
                        "JJ 5.2.b"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Can communicate with C2 by radio ONLY"
                }
            }
        ]
    },
```

```
    "Structure": {
        "Admin Nodes": [
            "NN 5.2",
            "OO 5.2",
            "QQ 5.2",
            "JJ 5.2",
            "JJ 5.2.a",
            "JJ 5.2.b",
            "PP 5.2"
        ],
        "Terminal Nodes": [
            "X 5.2",
            "XX 5.2"
        ],
        "Edges": {
            "X 5.2": [
                "Weapon System 5.2"
            ],
            "Weapon System 5.2": [
                "NN 5.2"
            ],
            "NN 5.2": [
                "15kW Generator Set 5.2"
            ],
            "15kW Generator Set 5.2": [
                "Generator Air Intake 5.2"
            ],
            "Generator Air Intake 5.2": [
                "Generator Fuel System 5.2"
            ],
            "Generator Fuel System 5.2": [
                "Diesel Engine 5.2"
            ],
            "Diesel Engine 5.2": [
                "Electric Generator 5.2"
            ],
            "Electric Generator 5.2": [
                "OO 5.2"
            ],
            "OO 5.2": [
                "Electronics System 5.2"
            ],
            "Electronics System 5.2": [
                "AC Cabinet 5.2",
                "Data Link Terminal 5.2"
            ],
            "AC Cabinet 5.2": [
                "Heater Control 5.2",
                "Compass 5.2"
            ],
            "Heater Control 5.2": [
                "Processor Card Cage 5.2"
            ],
            "Processor Card Cage 5.2": [
                "Ordnance Executive Processor Card 5.2"
            ],
            "Ordnance Executive Processor Card 5.2": [
```

```
                "Ordnance Interface Card 5.2"
            ],
            "Compass 5.2": [
                "GPS Receiver 5.2"
            ],
            "GPS Receiver 5.2": [
                "GPS Antenna 5.2"
            ],
            "GPS Antenna 5.2": [
                "Power Controls 5.2"
            ],
            "Power Controls 5.2": [
                "Motor Controls 5.2"
            ],
            "Motor Controls 5.2": [
                "Traverse & Elevation Mechanisms 5.2"
            ],
            "Traverse & Elevation Mechanisms 5.2": [
                "Azimuth Motor 5.2"
            ],
            "Azimuth Motor 5.2": [
                "Elevation Motor 5.2"
            ],
            "Elevation Motor 5.2": [
                "PP 5.2"
            ],
            "PP 5.2": [
                "XX 5.2"
            ],
            "Data Link Terminal 5.2": [
                "Digital Processor 5.2"
            ],
            "Digital Processor 5.2": [
                "Fiber Optic Modem 5.2",
                "VHF Radio 5.2"
            ],
            "Fiber Optic Modem 5.2": [
                "JJ 5.2.a"
            ],
            "JJ 5.2.a": [
                "JJ 5.2"
            ],
            "JJ 5.2": [
                "XX 5.2"
            ],
            "VHF Radio 5.2": [
                "EMP Suppressor 5.2"
            ],
            "EMP Suppressor 5.2": [
                "Radio Antenna 5.2"
            ],
            "Radio Antenna 5.2": [
                "JJ 5.2.b"
            ],
            "JJ 5.2.b": [
                "JJ 5.2"
            ],
```

```
            "Ordnance Interface Card 5.2": [
                "Fire Control 5.2"
            ],
            "Fire Control 5.2": [
                "Junction Box 5.2"
            ],
            "Junction Box 5.2": [
                "Data Cable 5.2.1",
                "Data Cable 5.2.2",
                "Data Cable 5.2.3"
            ],
            "Data Cable 5.2.1": [
                "Ordnance Relay Card 5.2.1",
                "Ordnance Relay Card 5.2.2",
                "Ordnance Relay Card 5.2.3",
                "Ordnance Relay Card 5.2.4"
            ],
            "Data Cable 5.2.2": [
                "Ordnance Relay Card 5.2.5",
                "Ordnance Relay Card 5.2.6",
                "Ordnance Relay Card 5.2.7",
                "Ordnance Relay Card 5.2.8"
            ],
            "Data Cable 5.2.3": [
                "Ordnance Relay Card 5.2.9",
                "Ordnance Relay Card 5.2.10",
                "Ordnance Relay Card 5.2.11",
                "Ordnance Relay Card 5.2.12"
            ],
            "Ordnance Relay Card 5.2.1": [
                "Canister 5.2.1"
            ],
            "Canister 5.2.1": [
                "Ordnance 5.2.1"
            ],
            "Ordnance 5.2.1": [
                "QQ 5.2"
            ],
            "Ordnance Relay Card 5.2.2": [
                "Canister 5.2.2"
            ],
            "Canister 5.2.2": [
                "Ordnance 5.2.2"
            ],
            "Ordnance 5.2.2": [
                "QQ 5.2"
            ],
            "Ordnance Relay Card 5.2.3": [
                "Canister 5.2.3"
            ],
            "Canister 5.2.3": [
                "Ordnance 5.2.3"
            ],
            "Ordnance 5.2.3": [
                "QQ 5.2"
            ],
            "Ordnance Relay Card 5.2.4": [
```

```
                "Canister 5.2.4"
            ],
            "Canister 5.2.4": [
                "Ordnance 5.2.4"
            ],
            "Ordnance 5.2.4": [
                "QQ 5.2"
            ],
            "Ordnance Relay Card 5.2.5": [
                "Canister 5.2.5"
            ],
            "Canister 5.2.5": [
                "Ordnance 5.2.5"
            ],
            "Ordnance 5.2.5": [
                "QQ 5.2"
            ],
            "Ordnance Relay Card 5.2.6": [
                "Canister 5.2.6"
            ],
            "Canister 5.2.6": [
                "Ordnance 5.2.6"
            ],
            "Ordnance 5.2.6": [
                "QQ 5.2"
            ],
            "Ordnance Relay Card 5.2.7": [
                "Canister 5.2.7"
            ],
            "Canister 5.2.7": [
                "Ordnance 5.2.7"
            ],
            "Ordnance 5.2.7": [
                "QQ 5.2"
            ],
            "Ordnance Relay Card 5.2.8": [
                "Canister 5.2.8"
            ],
            "Canister 5.2.8": [
                "Ordnance 5.2.8"
            ],
            "Ordnance 5.2.8": [
                "QQ 5.2"
            ],
            "Ordnance Relay Card 5.2.9": [
                "Canister 5.2.9"
            ],
            "Canister 5.2.9": [
                "Ordnance 5.2.9"
            ],
            "Ordnance 5.2.9": [
                "QQ 5.2"
            ],
            "Ordnance Relay Card 5.2.10": [
                "Canister 5.2.10"
            ],
            "Canister 5.2.10": [
```

```
                "Ordnance 5.2.10"
            ],
            "Ordnance 5.2.10": [
                "QQ 5.2"
            ],
            "Ordnance Relay Card 5.2.11": [
                "Canister 5.2.11"
            ],
            "Canister 5.2.11": [
                "Ordnance 5.2.11"
            ],
            "Ordnance 5.2.11": [
                "QQ 5.2"
            ],
            "Ordnance Relay Card 5.2.12": [
                "Canister 5.2.12"
            ],
            "Canister 5.2.12": [
                "Ordnance 5.2.12"
            ],
            "Ordnance 5.2.12": [
                "QQ 5.2"
            ],
            "QQ 5.2": [
                "XX 5.2"
            ]
        }
    },
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",
    "Maintainer": null,
    "Maintainer Title": null,
    "Maintainer Organization": null
}
```

Listing F.7: The weapon system 3 system data file for the Reference system of systems (Weapon_System_3.sdf.json)


```
{
    "HEADER COMMENTS": "Weapon System 3 of the Reference SOS",
    "System": {
        "Weapon System 5.3": {
            "ID": "System 5.3",
            "type": "equipment",
            "subtype": "weapon",
      "color":"#00AA64",
            "VNTK": null,
            "thresholds": {
                "static overpressure": 13.905187340022799,
                "dynamic pressure": 6.9525936700113995,
                "windspeed": 27.810374680045598,
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            }
        }
    },
    "Subsystems": {
        "15kW Generator Set 5.3": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                0,
                7.5,
                3.0
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 9.17669701208706,
                "dynamic pressure": 1.3109567160124371,
                "windspeed": "inf",
                "thermal fluence": 262.1913432024874,
                "total dose": 1310956.7160124371,
                "neutron dose": "inf",
                "neutron fluence": 1310956716012.437,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 13109567160.12437,
                "PD": "inf"
            },
            "Components": {
                "Generator Air Intake 5.3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -0.75,
                        7.25,
                        3.5
```

```
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 15.309626502262956,
                        "dynamic pressure": 3.827406625565739,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Generator Fuel System 5.3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        7.5,
                        2.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 27.78294023049891,
                        "dynamic pressure": 6.945735057624727,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Diesel Engine 5.3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        8.1,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 29.66430916874932,
                        "dynamic pressure": 7.41607729218733,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
```

```
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Electric Generator 5.3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0,
                        6.9,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 9.343665801380453,
                        "dynamic pressure": 1.3348094001972077,
                        "windspeed": "inf",
                        "thermal fluence": 266.96188003944155,
                        "total dose": 1334809.4001972077,
                        "neutron dose": "inf",
                        "neutron fluence": 1334809400197.2078,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 13348094001.972076,
                        "PD": "inf"
                    }
                }
            }
        },
        "Electronics System 5.3": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                -1.16,
                0.5,
                1.4
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 9.709647160759541,
                "dynamic pressure": 1.3870924515370773,
                "windspeed": "inf",
                "thermal fluence": 277.4184903074155,
                "total dose": 1387092.4515370773,
                "neutron dose": "inf",
                "neutron fluence": 1387092451537.0774,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 13870924515.370773,
                "PD": "inf"
            },
            "Components": {
                "AC Cabinet 5.3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
```

```
                        -1.2,
                        0.5,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 18.830506959143488,
                        "dynamic pressure": 4.707626739785872,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Data Link Terminal 5.3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.5,
                        1.4
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.03937397363622,
                        "dynamic pressure": 1.1484819962337456,
                        "windspeed": "inf",
                        "thermal fluence": 229.6963992467491,
                        "total dose": 1148481.9962337455,
                        "neutron dose": "inf",
                        "neutron fluence": 1148481996233.7456,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11484819962.337456,
                        "PD": "inf"
                    }
                },
                "Digital Processor 5.3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.25,
                        1.4
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.357472572894927,
                        "dynamic pressure": 1.051067510413561,
                        "windspeed": "inf",
                        "thermal fluence": 210.21350208271218,
                        "total dose": 1051067.510413561,
```

```
                        "neutron dose": "inf",
                        "neutron fluence": 1051067510413.5609,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10510675104.135609,
                        "PD": "inf"
                    }
                },
                "Fiber Optic Modem 5.3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.75,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 4.825086463159404,
                        "dynamic pressure": 0.6892980661656292,
                        "windspeed": "inf",
                        "thermal fluence": 137.85961323312583,
                        "total dose": 689298.0661656292,
                        "neutron dose": "inf",
                        "neutron fluence": 689298066165.6292,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 6892980661.656292,
                        "PD": "inf"
                    }
                },
                "VHF Radio 5.3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.25,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.285525536098458,
                        "dynamic pressure": 1.0407893622997797,
                        "windspeed": "inf",
                        "thermal fluence": 208.15787245995594,
                        "total dose": 1040789.3622997797,
                        "neutron dose": "inf",
                        "neutron fluence": 1040789362299.7797,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10407893622.997797,
                        "PD": "inf"
                    }
                },
                "EMP Suppressor 5.3": {
                    "ID": null,
                    "type": "equipment",
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                        "thermal fluence": "inf",
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                        "PD": "inf"
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                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12083264677.231003,
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                    }
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                    "thresholds": {
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                        "gamma ray dose rate": 10543057987.13037,
                        "PD": "inf"
                    }
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                "Ordnance Relay Card 5.3.4": {
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                    "thresholds": {
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                        "dynamic pressure": 1.375497880421464,
                        "windspeed": "inf",
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                        "gamma ray dose rate": 13754978804.21464,
                        "PD": "inf"
                    }
                },
                "Ordnance Relay Card 5.3.6": {
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                    "type": "equipment",
                    "subtype": "electrical",
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                        "neutron dose": "inf",
                        "neutron fluence": 883013631186.1788,
                        "gamma ray dose": "inf",
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                        "PD": "inf"
                    }
                },
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                    "subtype": "electrical",
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                        "PD": "inf"
                    }
                },
                "Ordnance Relay Card 5.3.8": {
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                        "neutron dose": "inf",
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                        "PD": "inf"
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                },
                "Ordnance Relay Card 5.3.9": {
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                    "subtype": "electrical",
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                        "neutron dose": "inf",
                        "neutron fluence": 918513001446.5137,
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                        "gamma ray dose rate": 9185130014.465137,
                        "PD": "inf"
                    }
                },
                "Ordnance Relay Card 5.3.10": {
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                    "subtype": "electrical",
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                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
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                        "windspeed": "inf",
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                        "neutron dose": "inf",
                        "neutron fluence": 942610059617.7047,
                        "gamma ray dose": "inf",
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                        "PD": "inf"
                    }
                },
                "Ordnance Relay Card 5.3.11": {
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                    "thresholds": {
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                        "gamma ray dose rate": 10697109437.5482,
                        "PD": "inf"
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                    "thresholds": {
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                    }
                },
                "Canister 5.3.1": {
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                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
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                        "PD": "inf"
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                        "gamma ray dose rate": "inf",
                        "PD": "inf"
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                },
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                    "thresholds": {
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                        "dynamic pressure": 3.9056703741259775,
                        "windspeed": "inf",
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                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Canister 5.3.4": {
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                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0.346,
                        -2.435,
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                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 6.050301769965348,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
```

```
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
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                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0.933,
                        -2.82,
                        5.322
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                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 15.312701031050482,
                        "dynamic pressure": 3.8281752577626205,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
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                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Canister 5.3.6": {
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                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
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                        -2.82,
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                    "VNTK": null,
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                        "dynamic pressure": 8.163304442518255,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
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                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
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                "Canister 5.3.7": {
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                    "subtype": "mechanical",
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```
                        -2.05,
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                        "gamma ray dose rate": "inf",
                        "PD": "inf"
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```
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                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
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                    }
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                    "thresholds": {
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                        "dynamic pressure": 4.621636251195043,
                        "windspeed": "inf",
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                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
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                    "subtype": "mechanical",
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                        "dynamic pressure": 3.2262792031584553,
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                    "relative position": [
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                        "windspeed": "inf",
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                        "gamma ray dose rate": "inf",
                        "PD": "inf"
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                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
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                    "VNTK": null,
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                        "dynamic pressure": 2.230073662018665,
                        "windspeed": "inf",
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                        "neutron dose": "inf",
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                        "gamma ray dose rate": 11150368310.093327,
                        "PD": "inf"
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                    "subtype": "ordnance",
                    "relative position": [
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                        "dynamic pressure": 2.219780376229773,
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                        "neutron dose": "inf",
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                        "PD": "inf"
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                    "type": "equipment",
                    "subtype": "ordnance",
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                        -2.438,
                        4.833
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                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 2.5352083749842196,
                        "windspeed": "inf",
                        "thermal fluence": 253.52083749842197,
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                        "neutron dose": "inf",
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                        "gamma ray dose rate": 12676041874.921099,
                        "PD": "inf"
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                },
                "Ordnance 5.3.4": {
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                        "thermal fluence": 223.46606922788345,
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                        "neutron fluence": 1117330346139.4172,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11173303461.394173,
                        "PD": "inf"
                    }
                },
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                    "ID": null,
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                    "subtype": "ordnance",
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                        "dynamic pressure": 1.25671373108228,
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                        "neutron dose": "inf",
                        "neutron fluence": 628356865541.14,
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                        "gamma ray dose rate": 6283568655.4114,
                        "PD": "inf"
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                    "ID": null,
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                    "subtype": "ordnance",
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                        "neutron dose": "inf",
                        "neutron fluence": 924966202322.9344,
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                        "gamma ray dose rate": 9249662023.229345,
                        "PD": "inf"
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                },
                "Ordnance 5.3.7": {
                    "ID": null,
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                    "subtype": "ordnance",
                    "relative position": [
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                        4.341
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                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 2.0883624559248837,
                        "windspeed": "inf",
                        "thermal fluence": 208.83624559248835,
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                        "neutron dose": "inf",
                        "neutron fluence": 1044181227962.4419,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10441812279.624418,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.3.8": {
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                    "type": "equipment",
                    "subtype": "ordnance",
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                        4.341
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                        "dynamic pressure": 2.1306973230963004,
                        "windspeed": "inf",
                        "thermal fluence": 213.06973230963004,
                        "total dose": 1065348.6615481502,
                        "neutron dose": "inf",
                        "neutron fluence": 1065348661548.1503,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10653486615.481503,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.3.9": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
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                    "thresholds": {
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                        "dynamic pressure": 2.5843379946913587,
                        "windspeed": "inf",
                        "thermal fluence": 258.43379946913586,
                        "total dose": 1292168.9973456794,
                        "neutron dose": "inf",
                        "neutron fluence": 1292168997345.6794,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12921689973.456793,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.3.10": {
                    "ID": null,
                    "type": "equipment",
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                    "thresholds": {
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                        "dynamic pressure": 2.7380127443030444,
                        "windspeed": "inf",
                        "thermal fluence": 273.80127443030443,
                        "total dose": 1369006.3721515222,
                        "neutron dose": "inf",
                        "neutron fluence": 1369006372151.5222,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 13690063721.515223,
                        "PD": "inf"
                    }
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                "Ordnance 5.3.11": {
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                    "subtype": "ordnance",
                    "relative position": [
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                        5.326
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                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 10.76243505011287,
                        "dynamic pressure": 3.0749814428893916,
                        "windspeed": "inf",
                        "thermal fluence": 307.49814428893916,
                        "total dose": 1537490.7214446957,
                        "neutron dose": "inf",
                        "neutron fluence": 1537490721444.6958,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 15374907214.446959,
                        "PD": "inf"
                    }
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                "Ordnance 5.3.12": {
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                    "subtype": "ordnance",
                    "relative position": [
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                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 2.811162268425248,
                        "windspeed": "inf",
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                        "thermal fluence": 281.11622684252484,
                        "total dose": 1405581.134212624,
                        "neutron dose": "inf",
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                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 14055811342.126242,
                        "PD": "inf"
                    }
                }
            }
        }
    },
    "capabilities": {
        "Power Self": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.3"
                    ],
                    "End Node": [
                        "OO 5.3"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Power available"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.3"
                    ],
                    "End Node": [
                        "OO 5.3"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Power NOT available"
                }
            }
        ],
        "Aims Self": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.3"
                    ],
                    "End Node": [
                        "PP 5.3"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Aims self"
                }
```

```
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.3"
                    ],
                    "End Node": [
                        "PP 5.3"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Does NOT aim self"
                }
            }
        ],
        "Fires Primary Weapon Ordnance": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.3"
                    ],
                    "End Node": [
                        "QQ 5.3"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Can fire one or more rounds of ordnance"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.3"
                    ],
                    "End Node": [
                        "QQ 5.3"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT fire primary weapon system"
                }
            }
        ],
        "Communicate with Command and Control System": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 5.3",
                        "X 5.3"
                    ],
                    "End Node": [
                        "JJ 5.3.a",
                        "JJ 5.3.b"
                    ],
```

```
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Communicates with C2 via cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.3"
                    ],
                    "End Node": [
                        "JJ 5.3"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT communicate with C2 system"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 5.3",
                        "X 5.3"
                    ],
                    "End Node": [
                        "JJ 5.3.a",
                        "JJ 5.3.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can communicate with C2 by cable ONLY"
                }
            },
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
                        "X 5.3",
                        "X 5.3"
                    ],
                    "End Node": [
                        "JJ 5.3.a",
                        "JJ 5.3.b"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Can communicate with C2 by radio ONLY"
                }
            }
        ]
    },
```

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    "Structure": {
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            "OO 5.3",
            "QQ 5.3",
            "JJ 5.3",
            "JJ 5.3.a",
            "JJ 5.3.b",
            "PP 5.3"
        ],
        "Terminal Nodes": [
            "X 5.3",
            "XX 5.3"
        ],
        "Edges": {
            "X 5.3": [
                "Weapon System 5.3"
            ],
            "Weapon System 5.3": [
                "NN 5.3"
            ],
            "NN 5.3": [
                "15kW Generator Set 5.3"
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            "15kW Generator Set 5.3": [
                "Generator Air Intake 5.3"
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            "Generator Air Intake 5.3": [
                "Generator Fuel System 5.3"
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                "Diesel Engine 5.3"
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                "Electric Generator 5.3"
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            "Electric Generator 5.3": [
                "OO 5.3"
            ],
            "OO 5.3": [
                "Electronics System 5.3"
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            "Electronics System 5.3": [
                "AC Cabinet 5.3",
                "Data Link Terminal 5.3"
            ],
            "AC Cabinet 5.3": [
                "Heater Control 5.3",
                "Compass 5.3"
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            "Heater Control 5.3": [
                "Processor Card Cage 5.3"
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            "Processor Card Cage 5.3": [
                "Ordnance Executive Processor Card 5.3"
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            "Compass 5.3": [
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            "GPS Receiver 5.3": [
                "GPS Antenna 5.3"
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                "Motor Controls 5.3"
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            "Azimuth Motor 5.3": [
                "Elevation Motor 5.3"
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            "Elevation Motor 5.3": [
                "PP 5.3"
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            "PP 5.3": [
                "XX 5.3"
            ],
            "Data Link Terminal 5.3": [
                "Digital Processor 5.3"
            ],
            "Digital Processor 5.3": [
                "Fiber Optic Modem 5.3",
                "VHF Radio 5.3"
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            "Fiber Optic Modem 5.3": [
                "JJ 5.3.a"
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            "JJ 5.3.a": [
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            ],
            "JJ 5.3": [
                "XX 5.3"
            ],
            "VHF Radio 5.3": [
                "EMP Suppressor 5.3"
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            "EMP Suppressor 5.3": [
                "Radio Antenna 5.3"
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            "Radio Antenna 5.3": [
                "JJ 5.3.b"
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            "JJ 5.3.b": [
                "JJ 5.3"
            ],
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                "Fire Control 5.3"
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            "Fire Control 5.3": [
                "Junction Box 5.3"
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            "Junction Box 5.3": [
                "Data Cable 5.3.1",
                "Data Cable 5.3.2",
                "Data Cable 5.3.3"
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                "Ordnance Relay Card 5.3.4"
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                "Ordnance Relay Card 5.3.12"
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            ],
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                "Ordnance 5.3.1"
            ],
            "Ordnance 5.3.1": [
                "QQ 5.3"
            ],
            "Ordnance Relay Card 5.3.2": [
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            ],
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            ],
            "Ordnance Relay Card 5.3.3": [
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            "Ordnance 5.3.3": [
                "QQ 5.3"
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            "Ordnance Relay Card 5.3.4": [
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            "Canister 5.3.4": [
                "Ordnance 5.3.4"
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            "Ordnance 5.3.4": [
                "QQ 5.3"
            ],
            "Ordnance Relay Card 5.3.5": [
                "Canister 5.3.5"
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                "Ordnance 5.3.5"
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            "Ordnance 5.3.5": [
                "QQ 5.3"
            ],
            "Ordnance Relay Card 5.3.6": [
                "Canister 5.3.6"
            ],
            "Canister 5.3.6": [
                "Ordnance 5.3.6"
            ],
            "Ordnance 5.3.6": [
                "QQ 5.3"
            ],
            "Ordnance Relay Card 5.3.7": [
                "Canister 5.3.7"
            ],
            "Canister 5.3.7": [
                "Ordnance 5.3.7"
            ],
            "Ordnance 5.3.7": [
                "QQ 5.3"
            ],
            "Ordnance Relay Card 5.3.8": [
                "Canister 5.3.8"
            ],
            "Canister 5.3.8": [
                "Ordnance 5.3.8"
            ],
            "Ordnance 5.3.8": [
                "QQ 5.3"
            ],
            "Ordnance Relay Card 5.3.9": [
                "Canister 5.3.9"
            ],
            "Canister 5.3.9": [
                "Ordnance 5.3.9"
            ],
            "Ordnance 5.3.9": [
                "QQ 5.3"
            ],
            "Ordnance Relay Card 5.3.10": [
                "Canister 5.3.10"
            ],
            "Canister 5.3.10": [
```

```
                "Ordnance 5.3.10"
            ],
            "Ordnance 5.3.10": [
                "QQ 5.3"
            ],
            "Ordnance Relay Card 5.3.11": [
                "Canister 5.3.11"
            ],
            "Canister 5.3.11": [
                "Ordnance 5.3.11"
            ],
            "Ordnance 5.3.11": [
                "QQ 5.3"
            ],
            "Ordnance Relay Card 5.3.12": [
                "Canister 5.3.12"
            ],
            "Canister 5.3.12": [
                "Ordnance 5.3.12"
            ],
            "Ordnance 5.3.12": [
                "QQ 5.3"
            ],
            "QQ 5.3": [
                "XX 5.3"
            ]
        }
    },
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",
    "Maintainer": null,
    "Maintainer Title": null,
    "Maintainer Organization": null
}
```

Listing F.8: The weapon system 4 system data file for the Reference system of systems (Weapon_System_4.sdf.json)


```
{
    "HEADER COMMENTS": "Weapon System 4 of the Reference SOS",
    "System": {
        "Weapon System 5.4": {
            "ID": "System 5.4",
            "type": "equipment",
            "subtype": "weapon",
      "color":"#00AA64",
            "VNTK": null,
            "thresholds": {
                "static overpressure": 15.028198449247583,
                "dynamic pressure": 7.514099224623791,
                "windspeed": 30.056396898495166,
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            }
        }
    },
    "Subsystems": {
        "15kW Generator Set 5.4": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                0,
                7.5,
                4.0
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 7.108547841609281,
                "dynamic pressure": 1.0155068345156115,
                "windspeed": "inf",
                "thermal fluence": 203.1013669031223,
                "total dose": 1015506.8345156115,
                "neutron dose": "inf",
                "neutron fluence": 1015506834515.6116,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 10155068345.156115,
                "PD": "inf"
            },
            "Components": {
                "Generator Air Intake 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -0.75,
                        7.25,
                        3.5
```

```
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 30.314637362655503,
                        "dynamic pressure": 7.578659340663876,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Generator Fuel System 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        7.5,
                        2.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 15.76012994465396,
                        "dynamic pressure": 3.94003248616349,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Diesel Engine 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        8.1,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 24.56700133034104,
                        "dynamic pressure": 6.14175033258526,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
```

```
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Electric Generator 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0,
                        6.9,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.561433750756427,
                        "dynamic pressure": 1.0802048215366324,
                        "windspeed": "inf",
                        "thermal fluence": 216.04096430732648,
                        "total dose": 1080204.8215366325,
                        "neutron dose": "inf",
                        "neutron fluence": 1080204821536.6324,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10802048215.366323,
                        "PD": "inf"
                    }
                }
            }
        },
        "Electronics System 5.4": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                -1.16,
                0.5,
                1.4
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 4.058068683098042,
                "dynamic pressure": 0.5797240975854345,
                "windspeed": "inf",
                "thermal fluence": 115.9448195170869,
                "total dose": 579724.0975854346,
                "neutron dose": "inf",
                "neutron fluence": 579724097585.4346,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 5797240975.854345,
                "PD": "inf"
            },
            "Components": {
                "AC Cabinet 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
```

```
                        -1.2,
                        0.5,
                        1.5
                    ],
                    "VNTK": null,
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                        "dynamic pressure": 4.365570093144867,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Data Link Terminal 5.4": {
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                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.5,
                        1.4
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.121872760836576,
                        "dynamic pressure": 1.017410394405225,
                        "windspeed": "inf",
                        "thermal fluence": 203.48207888104503,
                        "total dose": 1017410.3944052251,
                        "neutron dose": "inf",
                        "neutron fluence": 1017410394405.2251,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10174103944.05225,
                        "PD": "inf"
                    }
                },
                "Digital Processor 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.25,
                        1.4
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.902703876388209,
                        "dynamic pressure": 0.8432434109126012,
                        "windspeed": "inf",
                        "thermal fluence": 168.64868218252025,
                        "total dose": 843243.4109126013,
```

```
                        "neutron dose": "inf",
                        "neutron fluence": 843243410912.6012,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8432434109.126013,
                        "PD": "inf"
                    }
                },
                "Fiber Optic Modem 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
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                        0.75,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.201009876510168,
                        "dynamic pressure": 1.0287156966443098,
                        "windspeed": "inf",
                        "thermal fluence": 205.74313932886196,
                        "total dose": 1028715.6966443098,
                        "neutron dose": "inf",
                        "neutron fluence": 1028715696644.3098,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10287156966.443098,
                        "PD": "inf"
                    }
                },
                "VHF Radio 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.25,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.68027802987338,
                        "dynamic pressure": 1.097182575696197,
                        "windspeed": "inf",
                        "thermal fluence": 219.43651513923942,
                        "total dose": 1097182.575696197,
                        "neutron dose": "inf",
                        "neutron fluence": 1097182575696.197,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10971825756.961971,
                        "PD": "inf"
                    }
                },
                "EMP Suppressor 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
```

```
                    "relative position": [
                        1,
                        0,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.051033593320693,
                        "dynamic pressure": 0.8644333704743847,
                        "windspeed": "inf",
                        "thermal fluence": 172.88667409487695,
                        "total dose": 864433.3704743847,
                        "neutron dose": "inf",
                        "neutron fluence": 864433370474.3848,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8644333704.743847,
                        "PD": "inf"
                    }
                },
                "Radio Antenna 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "antenna",
                    "relative position": [
                        -1.5,
                        -2.5,
                        6.25
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.060693682737399,
                        "dynamic pressure": 0.722956240391057,
                        "windspeed": 14.45912480782114,
                        "thermal fluence": 144.5912480782114,
                        "total dose": 722956.240391057,
                        "neutron dose": "inf",
                        "neutron fluence": 722956240391.057,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7229562403.91057,
                        "PD": "inf"
                    }
                },
                "Compass 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -1.5,
                        -2.4,
                        2.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.952297586048758,
                        "dynamic pressure": 0.8503282265783939,
                        "windspeed": "inf",
                        "thermal fluence": 170.06564531567878,
```

```
                        "total dose": 850328.226578394,
                        "neutron dose": "inf",
                        "neutron fluence": 850328226578.3939,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8503282265.783939,
                        "PD": "inf"
                    }
                },
                "GPS Receiver 5.4": {
                    "ID": "DAGR",
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -1.5,
                        -2.9,
                        2.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.547795181325053,
                        "dynamic pressure": 0.9353993116178646,
                        "windspeed": "inf",
                        "thermal fluence": 187.0798623235729,
                        "total dose": 935399.3116178646,
                        "neutron dose": "inf",
                        "neutron fluence": 935399311617.8646,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9353993116.178646,
                        "PD": "inf"
                    }
                },
                "GPS Antenna 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "antenna",
                    "relative position": [
                        -1.5,
                        -2.5,
                        7.7
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.652904571459335,
                        "dynamic pressure": 0.950414938779905,
                        "windspeed": 19.0082987755981,
                        "thermal fluence": 190.082987755981,
                        "total dose": 950414.938779905,
                        "neutron dose": "inf",
                        "neutron fluence": 950414938779.905,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9504149387.79905,
                        "PD": "inf"
                    }
                },
                "Power Controls 5.4": {
                    "ID": null,
                    "type": "equipment",
```

```
                    "subtype": "electrical",
                    "relative position": [
                        -1,
                        0,
                        1.25
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.139511322167199,
                        "dynamic pressure": 0.7342159031667428,
                        "windspeed": "inf",
                        "thermal fluence": 146.84318063334857,
                        "total dose": 734215.9031667428,
                        "neutron dose": "inf",
                        "neutron fluence": 734215903166.7428,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7342159031.667428,
                        "PD": "inf"
                    }
                },
                "Motor Controls 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -1,
                        0.5,
                        1.25
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.472989687273219,
                        "dynamic pressure": 0.7818556696104598,
                        "windspeed": "inf",
                        "thermal fluence": 156.37113392209196,
                        "total dose": 781855.6696104598,
                        "neutron dose": "inf",
                        "neutron fluence": 781855669610.4598,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7818556696.104598,
                        "PD": "inf"
                    }
                },
                "Traverse & Elevation Mechanisms 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        -2.65,
                        2.22
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 24.42154530664405,
                        "dynamic pressure": 6.105386326661012,
                        "windspeed": "inf",
```

```
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Azimuth Motor 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0,
                        -3.5,
                        2.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.018448219662009,
                        "dynamic pressure": 1.0026354599517155,
                        "windspeed": "inf",
                        "thermal fluence": 200.5270919903431,
                        "total dose": 1002635.4599517155,
                        "neutron dose": "inf",
                        "neutron fluence": 1002635459951.7156,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10026354599.517155,
                        "PD": "inf"
                    }
                },
                "Elevation Motor 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0,
                        -2.5,
                        2.75
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.484511459510342,
                        "dynamic pressure": 1.2120730656443346,
                        "windspeed": "inf",
                        "thermal fluence": 242.4146131288669,
                        "total dose": 1212073.0656443345,
                        "neutron dose": "inf",
                        "neutron fluence": 1212073065644.3345,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12120730656.443346,
                        "PD": "inf"
                    }
                },
                "Heater Control 5.4": {
                    "ID": null,
```

```
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1,
                        -0.6,
                        1.25
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 11.954766582453557,
                        "dynamic pressure": 1.7078237974933652,
                        "windspeed": "inf",
                        "thermal fluence": 341.564759498673,
                        "total dose": 1707823.7974933651,
                        "neutron dose": "inf",
                        "neutron fluence": 1707823797493.3652,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 17078237974.933653,
                        "PD": "inf"
                    }
                },
                "Processor Card Cage 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -1.2,
                        0.75,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.646173099354369,
                        "dynamic pressure": 0.8065961570506242,
                        "windspeed": "inf",
                        "thermal fluence": 161.31923141012484,
                        "total dose": 806596.1570506241,
                        "neutron dose": "inf",
                        "neutron fluence": 806596157050.6241,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8065961570.506242,
                        "PD": "inf"
                    }
                },
                "Ordnance Executive Processor Card 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.5,
                        -3.8,
                        2.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.385244800265664,
                        "dynamic pressure": 0.9121778286093805,
```

```
                        "windspeed": "inf",
                        "thermal fluence": 182.4355657218761,
                        "total dose": 912177.8286093804,
                        "neutron dose": "inf",
                        "neutron fluence": 912177828609.3805,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9121778286.093805,
                        "PD": "inf"
                    }
                },
                "Ordnance Interface Card 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0.48,
                        -3.8,
                        0
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.440130773453332,
                        "dynamic pressure": 1.2057329676361903,
                        "windspeed": "inf",
                        "thermal fluence": 241.14659352723805,
                        "total dose": 1205732.9676361904,
                        "neutron dose": "inf",
                        "neutron fluence": 1205732967636.1904,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12057329676.361902,
                        "PD": "inf"
                    }
                }
            }
        },
        "Fire Control 5.4": {
            "ID": "Ordanance fire controls",
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                -1.16,
                0.3,
                1.42
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 5.30650952951621,
                "dynamic pressure": 0.7580727899308871,
                "windspeed": "inf",
                "thermal fluence": 151.61455798617743,
                "total dose": 758072.7899308872,
                "neutron dose": "inf",
                "neutron fluence": 758072789930.8871,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 7580727899.308871,
                "PD": "inf"
            },
```

```
            "Components": {
                "Junction Box 5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        -3.7,
                        2.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 17.47471723748119,
                        "dynamic pressure": 4.368679309370298,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Data Cable 5.4.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -0.64,
                        -4.36,
                        2.93
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 18.13155609743848,
                        "dynamic pressure": 4.53288902435962,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Data Cable 5.4.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0.64,
                        -4.36,
                        2.93
                    ],
                    "VNTK": null,
```

```
                    "thresholds": {
                        "static overpressure": 34.909352526807474,
                        "dynamic pressure": 8.727338131701869,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Data Cable 5.4.3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        -4.74,
                        3.42
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 23.63600514887721,
                        "dynamic pressure": 5.9090012872193025,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
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                        "dynamic pressure": 2.375044972687039,
                        "windspeed": "inf",
                        "thermal fluence": 237.5044972687039,
                        "total dose": 1187522.4863435195,
                        "neutron dose": "inf",
                        "neutron fluence": 1187522486343.5195,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11875224863.435194,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.4.11": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.93,
                        -2.823,
                        5.326
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 4.306572044954283,
                        "dynamic pressure": 1.2304491557012238,
                        "windspeed": "inf",
                        "thermal fluence": 123.04491557012238,
                        "total dose": 615224.5778506119,
                        "neutron dose": "inf",
                        "neutron fluence": 615224577850.6119,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 6152245778.506119,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.4.12": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.343,
                        -2.823,
                        5.326
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.266055870241042,
                        "dynamic pressure": 2.361730248640298,
                        "windspeed": "inf",
```

```
                        "thermal fluence": 236.17302486402977,
                        "total dose": 1180865.124320149,
                        "neutron dose": "inf",
                        "neutron fluence": 1180865124320.149,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11808651243.201488,
                        "PD": "inf"
                    }
                }
            }
        }
    },
    "capabilities": {
        "Power Self": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.4"
                    ],
                    "End Node": [
                        "OO 5.4"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Power available"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.4"
                    ],
                    "End Node": [
                        "OO 5.4"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Power NOT available"
                }
            }
        ],
        "Aims Self": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.4"
                    ],
                    "End Node": [
                        "PP 5.4"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Aims self"
                }
```

```
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.4"
                    ],
                    "End Node": [
                        "PP 5.4"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Does NOT aim self"
                }
            }
        ],
        "Fires Primary Weapon Ordnance": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.4"
                    ],
                    "End Node": [
                        "QQ 5.4"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Can fire one or more rounds of ordnance"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.4"
                    ],
                    "End Node": [
                        "QQ 5.4"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT fire primary weapon system"
                }
            }
        ],
        "Communicate with Command and Control System": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 5.4",
                        "X 5.4"
                    ],
                    "End Node": [
                        "JJ 5.4.a",
                        "JJ 5.4.b"
                    ],
```

```
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Communicates with C2 via cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.4"
                    ],
                    "End Node": [
                        "JJ 5.4"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT communicate with C2 system"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 5.4",
                        "X 5.4"
                    ],
                    "End Node": [
                        "JJ 5.4.a",
                        "JJ 5.4.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can communicate with C2 by cable ONLY"
                }
            },
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
                        "X 5.4",
                        "X 5.4"
                    ],
                    "End Node": [
                        "JJ 5.4.a",
                        "JJ 5.4.b"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Can communicate with C2 by radio ONLY"
                }
            }
        ]
    },
```

```
    "Structure": {
        "Admin Nodes": [
            "NN 5.4",
            "OO 5.4",
            "QQ 5.4",
            "JJ 5.4",
            "JJ 5.4.a",
            "JJ 5.4.b",
            "PP 5.4"
        ],
        "Terminal Nodes": [
            "X 5.4",
            "XX 5.4"
        ],
        "Edges": {
            "X 5.4": [
                "Weapon System 5.4"
            ],
            "Weapon System 5.4": [
                "NN 5.4"
            ],
            "NN 5.4": [
                "15kW Generator Set 5.4"
            ],
            "15kW Generator Set 5.4": [
                "Generator Air Intake 5.4"
            ],
            "Generator Air Intake 5.4": [
                "Generator Fuel System 5.4"
            ],
            "Generator Fuel System 5.4": [
                "Diesel Engine 5.4"
            ],
            "Diesel Engine 5.4": [
                "Electric Generator 5.4"
            ],
            "Electric Generator 5.4": [
                "OO 5.4"
            ],
            "OO 5.4": [
                "Electronics System 5.4"
            ],
            "Electronics System 5.4": [
                "AC Cabinet 5.4",
                "Data Link Terminal 5.4"
            ],
            "AC Cabinet 5.4": [
                "Heater Control 5.4",
                "Compass 5.4"
            ],
            "Heater Control 5.4": [
                "Processor Card Cage 5.4"
            ],
            "Processor Card Cage 5.4": [
                "Ordnance Executive Processor Card 5.4"
            ],
            "Ordnance Executive Processor Card 5.4": [
```

```
                "Ordnance Interface Card 5.4"
            ],
            "Compass 5.4": [
                "GPS Receiver 5.4"
            ],
            "GPS Receiver 5.4": [
                "GPS Antenna 5.4"
            ],
            "GPS Antenna 5.4": [
                "Power Controls 5.4"
            ],
            "Power Controls 5.4": [
                "Motor Controls 5.4"
            ],
            "Motor Controls 5.4": [
                "Traverse & Elevation Mechanisms 5.4"
            ],
            "Traverse & Elevation Mechanisms 5.4": [
                "Azimuth Motor 5.4"
            ],
            "Azimuth Motor 5.4": [
                "Elevation Motor 5.4"
            ],
            "Elevation Motor 5.4": [
                "PP 5.4"
            ],
            "PP 5.4": [
                "XX 5.4"
            ],
            "Data Link Terminal 5.4": [
                "Digital Processor 5.4"
            ],
            "Digital Processor 5.4": [
                "Fiber Optic Modem 5.4",
                "VHF Radio 5.4"
            ],
            "Fiber Optic Modem 5.4": [
                "JJ 5.4.a"
            ],
            "JJ 5.4.a": [
                "JJ 5.4"
            ],
            "JJ 5.4": [
                "XX 5.4"
            ],
            "VHF Radio 5.4": [
                "EMP Suppressor 5.4"
            ],
            "EMP Suppressor 5.4": [
                "Radio Antenna 5.4"
            ],
            "Radio Antenna 5.4": [
                "JJ 5.4.b"
            ],
            "JJ 5.4.b": [
                "JJ 5.4"
            ],
```

```
            "Ordnance Interface Card 5.4": [
                "Fire Control 5.4"
            ],
            "Fire Control 5.4": [
                "Junction Box 5.4"
            ],
            "Junction Box 5.4": [
                "Data Cable 5.4.1",
                "Data Cable 5.4.2",
                "Data Cable 5.4.3"
            ],
            "Data Cable 5.4.1": [
                "Ordnance Relay Card 5.4.1",
                "Ordnance Relay Card 5.4.2",
                "Ordnance Relay Card 5.4.3",
                "Ordnance Relay Card 5.4.4"
            ],
            "Data Cable 5.4.2": [
                "Ordnance Relay Card 5.4.5",
                "Ordnance Relay Card 5.4.6",
                "Ordnance Relay Card 5.4.7",
                "Ordnance Relay Card 5.4.8"
            ],
            "Data Cable 5.4.3": [
                "Ordnance Relay Card 5.4.9",
                "Ordnance Relay Card 5.4.10",
                "Ordnance Relay Card 5.4.11",
                "Ordnance Relay Card 5.4.12"
            ],
            "Ordnance Relay Card 5.4.1": [
                "Canister 5.4.1"
            ],
            "Canister 5.4.1": [
                "Ordnance 5.4.1"
            ],
            "Ordnance 5.4.1": [
                "QQ 5.4"
            ],
            "Ordnance Relay Card 5.4.2": [
                "Canister 5.4.2"
            ],
            "Canister 5.4.2": [
                "Ordnance 5.4.2"
            ],
            "Ordnance 5.4.2": [
                "QQ 5.4"
            ],
            "Ordnance Relay Card 5.4.3": [
                "Canister 5.4.3"
            ],
            "Canister 5.4.3": [
                "Ordnance 5.4.3"
            ],
            "Ordnance 5.4.3": [
                "QQ 5.4"
            ],
            "Ordnance Relay Card 5.4.4": [
```

```
                "Canister 5.4.4"
            ],
            "Canister 5.4.4": [
                "Ordnance 5.4.4"
            ],
            "Ordnance 5.4.4": [
                "QQ 5.4"
            ],
            "Ordnance Relay Card 5.4.5": [
                "Canister 5.4.5"
            ],
            "Canister 5.4.5": [
                "Ordnance 5.4.5"
            ],
            "Ordnance 5.4.5": [
                "QQ 5.4"
            ],
            "Ordnance Relay Card 5.4.6": [
                "Canister 5.4.6"
            ],
            "Canister 5.4.6": [
                "Ordnance 5.4.6"
            ],
            "Ordnance 5.4.6": [
                "QQ 5.4"
            ],
            "Ordnance Relay Card 5.4.7": [
                "Canister 5.4.7"
            ],
            "Canister 5.4.7": [
                "Ordnance 5.4.7"
            ],
            "Ordnance 5.4.7": [
                "QQ 5.4"
            ],
            "Ordnance Relay Card 5.4.8": [
                "Canister 5.4.8"
            ],
            "Canister 5.4.8": [
                "Ordnance 5.4.8"
            ],
            "Ordnance 5.4.8": [
                "QQ 5.4"
            ],
            "Ordnance Relay Card 5.4.9": [
                "Canister 5.4.9"
            ],
            "Canister 5.4.9": [
                "Ordnance 5.4.9"
            ],
            "Ordnance 5.4.9": [
                "QQ 5.4"
            ],
            "Ordnance Relay Card 5.4.10": [
                "Canister 5.4.10"
            ],
            "Canister 5.4.10": [
```

```
                "Ordnance 5.4.10"
            ],
            "Ordnance 5.4.10": [
                "QQ 5.4"
            ],
            "Ordnance Relay Card 5.4.11": [
                "Canister 5.4.11"
            ],
            "Canister 5.4.11": [
                "Ordnance 5.4.11"
            ],
            "Ordnance 5.4.11": [
                "QQ 5.4"
            ],
            "Ordnance Relay Card 5.4.12": [
                "Canister 5.4.12"
            ],
            "Canister 5.4.12": [
                "Ordnance 5.4.12"
            ],
            "Ordnance 5.4.12": [
                "QQ 5.4"
            ],
            "QQ 5.4": [
                "XX 5.4"
            ]
        }
    },
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",
    "Maintainer": null,
    "Maintainer Title": null,
    "Maintainer Organization": null
}
```

Listing F.9: The weapon system 5 system data file for the Reference system of systems (Weapon_System_5.sdf.json)


```
{
    "HEADER COMMENTS": "Weapon System 5 of the Reference SOS",
    "System": {
        "Weapon System 5.5": {
            "ID": "System 5.5",
            "type": "equipment",
            "subtype": "weapon",
      "color":"#00AA64",
            "VNTK": null,
            "thresholds": {
                "static overpressure": 19.833765161776775,
                "dynamic pressure": 9.916882580888387,
                "windspeed": 39.66753032355355,
                "thermal fluence": "inf",
                "total dose": "inf",
                "neutron dose": "inf",
                "neutron fluence": "inf",
                "gamma ray dose": "inf",
                "gamma ray dose rate": "inf",
                "PD": "inf"
            }
        }
    },
    "Subsystems": {
        "15kW Generator Set 5.5": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                0,
                7.5,
                4.0
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 4.37977054712969,
                "dynamic pressure": 0.6256815067328128,
                "windspeed": "inf",
                "thermal fluence": 125.13630134656255,
                "total dose": 625681.5067328127,
                "neutron dose": "inf",
                "neutron fluence": 625681506732.8127,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 6256815067.328128,
                "PD": "inf"
            },
            "Components": {
                "Generator Air Intake 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -0.75,
                        7.25,
                        3.5
```

```
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 18.52192804323692,
                        "dynamic pressure": 4.63048201080923,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Generator Fuel System 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        7.5,
                        2.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 20.489584503108333,
                        "dynamic pressure": 5.122396125777083,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Diesel Engine 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        0,
                        8.1,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 10.16942065181075,
                        "dynamic pressure": 2.5423551629526875,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
```

```
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Electric Generator 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        0,
                        6.9,
                        3.2
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 9.487949743203545,
                        "dynamic pressure": 1.3554213918862208,
                        "windspeed": "inf",
                        "thermal fluence": 271.0842783772442,
                        "total dose": 1355421.3918862208,
                        "neutron dose": "inf",
                        "neutron fluence": 1355421391886.2207,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 13554213918.862207,
                        "PD": "inf"
                    }
                }
            }
        },
        "Electronics System 5.5": {
            "ID": null,
            "type": "equipment",
            "subtype": "electrical",
            "relative position": [
                -1.16,
                0.5,
                1.4
            ],
            "VNTK": null,
            "thresholds": {
                "static overpressure": 8.065355649976954,
                "dynamic pressure": 1.152193664282422,
                "windspeed": "inf",
                "thermal fluence": 230.4387328564844,
                "total dose": 1152193.664282422,
                "neutron dose": "inf",
                "neutron fluence": 1152193664282.4219,
                "gamma ray dose": "inf",
                "gamma ray dose rate": 11521936642.82422,
                "PD": "inf"
            },
            "Components": {
                "AC Cabinet 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
```

```
                        -1.2,
                        0.5,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 12.640210482263193,
                        "dynamic pressure": 3.160052620565798,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Data Link Terminal 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.5,
                        1.4
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.353683562019016,
                        "dynamic pressure": 1.1933833660027167,
                        "windspeed": "inf",
                        "thermal fluence": 238.67667320054332,
                        "total dose": 1193383.3660027166,
                        "neutron dose": "inf",
                        "neutron fluence": 1193383366002.7166,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11933833660.027166,
                        "PD": "inf"
                    }
                },
                "Digital Processor 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.25,
                        1.4
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.935547289230692,
                        "dynamic pressure": 0.990792469890099,
                        "windspeed": "inf",
                        "thermal fluence": 198.15849397801978,
                        "total dose": 990792.4698900989,
```

```
                        "neutron dose": "inf",
                        "neutron fluence": 990792469890.099,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9907924698.90099,
                        "PD": "inf"
                    }
                },
                "Fiber Optic Modem 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.75,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.816008203070389,
                        "dynamic pressure": 1.116572600438627,
                        "windspeed": "inf",
                        "thermal fluence": 223.31452008772538,
                        "total dose": 1116572.600438627,
                        "neutron dose": "inf",
                        "neutron fluence": 1116572600438.627,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11165726004.386269,
                        "PD": "inf"
                    }
                },
                "VHF Radio 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        1.16,
                        0.25,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.8166693600475545,
                        "dynamic pressure": 0.973809908578222,
                        "windspeed": "inf",
                        "thermal fluence": 194.7619817156444,
                        "total dose": 973809.908578222,
                        "neutron dose": "inf",
                        "neutron fluence": 973809908578.222,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 9738099085.78222,
                        "PD": "inf"
                    }
                },
                "EMP Suppressor 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
```

```
                    "relative position": [
                        1,
                        0,
                        1.5
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.720985296587791,
                        "dynamic pressure": 1.2458550423696844,
                        "windspeed": "inf",
                        "thermal fluence": 249.17100847393687,
                        "total dose": 1245855.0423696844,
                        "neutron dose": "inf",
                        "neutron fluence": 1245855042369.6843,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12458550423.696844,
                        "PD": "inf"
                    }
                },
                "Radio Antenna 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "antenna",
                    "relative position": [
                        -1.5,
                        -2.5,
                        6.25
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.789249346318614,
                        "dynamic pressure": 1.1127499066169448,
                        "windspeed": 22.254998132338898,
                        "thermal fluence": 222.54998132338898,
                        "total dose": 1112749.9066169448,
                        "neutron dose": "inf",
                        "neutron fluence": 1112749906616.9448,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11127499066.169449,
                        "PD": "inf"
                    }
                },
                "Compass 5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -1.5,
                        -2.4,
                        2.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.540649283095151,
                        "dynamic pressure": 1.0772356118707358,
                        "windspeed": "inf",
                        "thermal fluence": 215.44712237414717,
```

```
                        "total dose": 1077235.611870736,
                        "neutron dose": "inf",
                        "neutron fluence": 1077235611870.7358,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10772356118.707357,
                        "PD": "inf"
                    }
                },
                "GPS Receiver 5.5": {
                    "ID": "DAGR",
                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
                        -1.5,
                        -2.9,
                        2.1
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 6.559815290420896,
                        "dynamic pressure": 0.937116470060128,
                        "windspeed": "inf",
                        "thermal fluence": 187.4232940120256,
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                        "PD": "inf"
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                        "PD": "inf"
                    }
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                        "PD": "inf"
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                    "thresholds": {
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                        "dynamic pressure": 6.409708079921408,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Canister 5.5.8": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -0.346,
                        -2.05,
                        4.337
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 21.77222963807521,
                        "dynamic pressure": 5.4430574095188025,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Canister 5.5.9": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -0.933,
                        -2.435,
                        4.829
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 21.576017065186267,
                        "dynamic pressure": 5.394004266296567,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
```

```
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Canister 5.5.10": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -0.346,
                        -2.435,
                        4.829
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 17.56086621169416,
                        "dynamic pressure": 4.39021655292354,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Canister 5.5.11": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
                        -0.933,
                        -2.82,
                        5.322
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 11.458468957703737,
                        "dynamic pressure": 2.864617239425934,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Canister 5.5.12": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
```

```
                        -0.346,
                        -2.82,
                        5.322
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 28.25743413404382,
                        "dynamic pressure": 7.064358533510955,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
                        "neutron dose": "inf",
                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.1": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        0.349,
                        -2.053,
                        4.341
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.7737354486679395,
                        "dynamic pressure": 1.6496386996194112,
                        "windspeed": "inf",
                        "thermal fluence": 164.96386996194113,
                        "total dose": 824819.3498097056,
                        "neutron dose": "inf",
                        "neutron fluence": 824819349809.7056,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8248193498.097056,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.2": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        0.936,
                        -2.053,
                        4.341
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.774954144525699,
                        "dynamic pressure": 1.649986898435914,
                        "windspeed": "inf",
                        "thermal fluence": 164.9986898435914,
                        "total dose": 824993.449217957,
```

```
                        "neutron dose": "inf",
                        "neutron fluence": 824993449217.957,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8249934492.17957,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.3": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        0.936,
                        -2.438,
                        4.833
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 4.25000951566881,
                        "dynamic pressure": 1.2142884330482315,
                        "windspeed": "inf",
                        "thermal fluence": 121.42884330482315,
                        "total dose": 607144.2165241158,
                        "neutron dose": "inf",
                        "neutron fluence": 607144216524.1157,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 6071442165.241158,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.4": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        0.349,
                        -2.438,
                        4.833
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.58987899743159,
                        "dynamic pressure": 1.5971082849804543,
                        "windspeed": "inf",
                        "thermal fluence": 159.71082849804543,
                        "total dose": 798554.1424902271,
                        "neutron dose": "inf",
                        "neutron fluence": 798554142490.2272,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7985541424.902271,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.5": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
```

```
                    "relative position": [
                        0.936,
                        -2.823,
                        5.326
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.798903368353713,
                        "dynamic pressure": 1.6568295338153465,
                        "windspeed": "inf",
                        "thermal fluence": 165.68295338153465,
                        "total dose": 828414.7669076732,
                        "neutron dose": "inf",
                        "neutron fluence": 828414766907.6732,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 8284147669.076733,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.6": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        0.349,
                        -2.823,
                        5.326
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.541498238154608,
                        "dynamic pressure": 2.154713782329888,
                        "windspeed": "inf",
                        "thermal fluence": 215.4713782329888,
                        "total dose": 1077356.891164944,
                        "neutron dose": "inf",
                        "neutron fluence": 1077356891164.9441,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10773568911.64944,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.7": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.93,
                        -2.053,
                        4.341
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 10.404994642379911,
                        "dynamic pressure": 2.972855612108546,
                        "windspeed": "inf",
                        "thermal fluence": 297.2855612108546,
```

```
                        "total dose": 1486427.8060542732,
                        "neutron dose": "inf",
                        "neutron fluence": 1486427806054.273,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 14864278060.54273,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.8": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.343,
                        -2.053,
                        4.341
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.258158266942694,
                        "dynamic pressure": 2.3594737905550556,
                        "windspeed": "inf",
                        "thermal fluence": 235.94737905550556,
                        "total dose": 1179736.8952775279,
                        "neutron dose": "inf",
                        "neutron fluence": 1179736895277.5278,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 11797368952.775278,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.9": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.93,
                        -2.438,
                        4.833
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 7.170700546220814,
                        "dynamic pressure": 2.0487715846345185,
                        "windspeed": "inf",
                        "thermal fluence": 204.87715846345185,
                        "total dose": 1024385.7923172592,
                        "neutron dose": "inf",
                        "neutron fluence": 1024385792317.2593,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 10243857923.172592,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.10": {
                    "ID": null,
                    "type": "equipment",
```

```
                    "subtype": "ordnance",
                    "relative position": [
                        -0.343,
                        -2.438,
                        4.833
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 8.698863608596113,
                        "dynamic pressure": 2.4853896024560322,
                        "windspeed": "inf",
                        "thermal fluence": 248.53896024560322,
                        "total dose": 1242694.8012280161,
                        "neutron dose": "inf",
                        "neutron fluence": 1242694801228.016,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 12426948012.28016,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.11": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.93,
                        -2.823,
                        5.326
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 4.862597706816311,
                        "dynamic pressure": 1.389313630518946,
                        "windspeed": "inf",
                        "thermal fluence": 138.9313630518946,
                        "total dose": 694656.8152594729,
                        "neutron dose": "inf",
                        "neutron fluence": 694656815259.473,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 6946568152.594729,
                        "PD": "inf"
                    }
                },
                "Ordnance 5.5.12": {
                    "ID": null,
                    "type": "equipment",
                    "subtype": "ordnance",
                    "relative position": [
                        -0.343,
                        -2.823,
                        5.326
                    ],
                    "VNTK": null,
                    "thresholds": {
                        "static overpressure": 5.457025722432388,
                        "dynamic pressure": 1.5591502064092537,
                        "windspeed": "inf",
```

```
                        "thermal fluence": 155.91502064092538,
                        "total dose": 779575.1032046268,
                        "neutron dose": "inf",
                        "neutron fluence": 779575103204.6268,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7795751032.046268,
                        "PD": "inf"
                    }
                }
            }
        }
    },
    "capabilities": {
        "Power Self": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.5"
                    ],
                    "End Node": [
                        "OO 5.5"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Power available"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.5"
                    ],
                    "End Node": [
                        "OO 5.5"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Power NOT available"
                }
            }
        ],
        "Aims Self": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.5"
                    ],
                    "End Node": [
                        "PP 5.5"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Aims self"
                }
```

```
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.5"
                    ],
                    "End Node": [
                        "PP 5.5"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Does NOT aim self"
                }
            }
        ],
        "Fires Primary Weapon Ordnance": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.5"
                    ],
                    "End Node": [
                        "QQ 5.5"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Can fire one or more rounds of ordnance"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.5"
                    ],
                    "End Node": [
                        "QQ 5.5"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT fire primary weapon system"
                }
            }
        ],
        "Communicate with Command and Control System": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 5.5",
                        "X 5.5"
                    ],
                    "End Node": [
                        "JJ 5.5.a",
                        "JJ 5.5.b"
                    ],
```

```
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Communicates with C2 via cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.5"
                    ],
                    "End Node": [
                        "JJ 5.5"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT communicate with C2 system"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 5.5",
                        "X 5.5"
                    ],
                    "End Node": [
                        "JJ 5.5.a",
                        "JJ 5.5.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can communicate with C2 by cable ONLY"
                }
            },
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
                        "X 5.5",
                        "X 5.5"
                    ],
                    "End Node": [
                        "JJ 5.5.a",
                        "JJ 5.5.b"
                    ],
                    "Has Path": [
                        false,
                        true
                    ],
                    "Comment": "Can communicate with C2 by radio ONLY"
                }
            }
        ]
    },
```

```
    "Structure": {
        "Admin Nodes": [
            "NN 5.5",
            "OO 5.5",
            "QQ 5.5",
            "JJ 5.5",
            "JJ 5.5.a",
            "JJ 5.5.b",
            "PP 5.5"
        ],
        "Terminal Nodes": [
            "X 5.5",
            "XX 5.5"
        ],
        "Edges": {
            "X 5.5": [
                "Weapon System 5.5"
            ],
            "Weapon System 5.5": [
                "NN 5.5"
            ],
            "NN 5.5": [
                "15kW Generator Set 5.5"
            ],
            "15kW Generator Set 5.5": [
                "Generator Air Intake 5.5"
            ],
            "Generator Air Intake 5.5": [
                "Generator Fuel System 5.5"
            ],
            "Generator Fuel System 5.5": [
                "Diesel Engine 5.5"
            ],
            "Diesel Engine 5.5": [
                "Electric Generator 5.5"
            ],
            "Electric Generator 5.5": [
                "OO 5.5"
            ],
            "OO 5.5": [
                "Electronics System 5.5"
            ],
            "Electronics System 5.5": [
                "AC Cabinet 5.5",
                "Data Link Terminal 5.5"
            ],
            "AC Cabinet 5.5": [
                "Heater Control 5.5",
                "Compass 5.5"
            ],
            "Heater Control 5.5": [
                "Processor Card Cage 5.5"
            ],
            "Processor Card Cage 5.5": [
                "Ordnance Executive Processor Card 5.5"
            ],
            "Ordnance Executive Processor Card 5.5": [
```

```
                "Ordnance Interface Card 5.5"
            ],
            "Compass 5.5": [
                "GPS Receiver 5.5"
            ],
            "GPS Receiver 5.5": [
                "GPS Antenna 5.5"
            ],
            "GPS Antenna 5.5": [
                "Power Controls 5.5"
            ],
            "Power Controls 5.5": [
                "Motor Controls 5.5"
            ],
            "Motor Controls 5.5": [
                "Traverse & Elevation Mechanisms 5.5"
            ],
            "Traverse & Elevation Mechanisms 5.5": [
                "Azimuth Motor 5.5"
            ],
            "Azimuth Motor 5.5": [
                "Elevation Motor 5.5"
            ],
            "Elevation Motor 5.5": [
                "PP 5.5"
            ],
            "PP 5.5": [
                "XX 5.5"
            ],
            "Data Link Terminal 5.5": [
                "Digital Processor 5.5"
            ],
            "Digital Processor 5.5": [
                "Fiber Optic Modem 5.5",
                "VHF Radio 5.5"
            ],
            "Fiber Optic Modem 5.5": [
                "JJ 5.5.a"
            ],
            "JJ 5.5.a": [
                "JJ 5.5"
            ],
            "JJ 5.5": [
                "XX 5.5"
            ],
            "VHF Radio 5.5": [
                "EMP Suppressor 5.5"
            ],
            "EMP Suppressor 5.5": [
                "Radio Antenna 5.5"
            ],
            "Radio Antenna 5.5": [
                "JJ 5.5.b"
            ],
            "JJ 5.5.b": [
                "JJ 5.5"
            ],
```

```
            "Ordnance Interface Card 5.5": [
                "Fire Control 5.5"
            ],
            "Fire Control 5.5": [
                "Junction Box 5.5"
            ],
            "Junction Box 5.5": [
                "Data Cable 5.5.1",
                "Data Cable 5.5.2",
                "Data Cable 5.5.3"
            ],
            "Data Cable 5.5.1": [
                "Ordnance Relay Card 5.5.1",
                "Ordnance Relay Card 5.5.2",
                "Ordnance Relay Card 5.5.3",
                "Ordnance Relay Card 5.5.4"
            ],
            "Data Cable 5.5.2": [
                "Ordnance Relay Card 5.5.5",
                "Ordnance Relay Card 5.5.6",
                "Ordnance Relay Card 5.5.7",
                "Ordnance Relay Card 5.5.8"
            ],
            "Data Cable 5.5.3": [
                "Ordnance Relay Card 5.5.9",
                "Ordnance Relay Card 5.5.10",
                "Ordnance Relay Card 5.5.11",
                "Ordnance Relay Card 5.5.12"
            ],
            "Ordnance Relay Card 5.5.1": [
                "Canister 5.5.1"
            ],
            "Canister 5.5.1": [
                "Ordnance 5.5.1"
            ],
            "Ordnance 5.5.1": [
                "QQ 5.5"
            ],
            "Ordnance Relay Card 5.5.2": [
                "Canister 5.5.2"
            ],
            "Canister 5.5.2": [
                "Ordnance 5.5.2"
            ],
            "Ordnance 5.5.2": [
                "QQ 5.5"
            ],
            "Ordnance Relay Card 5.5.3": [
                "Canister 5.5.3"
            ],
            "Canister 5.5.3": [
                "Ordnance 5.5.3"
            ],
            "Ordnance 5.5.3": [
                "QQ 5.5"
            ],
            "Ordnance Relay Card 5.5.4": [
```

```
                "Canister 5.5.4"
            ],
            "Canister 5.5.4": [
                "Ordnance 5.5.4"
            ],
            "Ordnance 5.5.4": [
                "QQ 5.5"
            ],
            "Ordnance Relay Card 5.5.5": [
                "Canister 5.5.5"
            ],
            "Canister 5.5.5": [
                "Ordnance 5.5.5"
            ],
            "Ordnance 5.5.5": [
                "QQ 5.5"
            ],
            "Ordnance Relay Card 5.5.6": [
                "Canister 5.5.6"
            ],
            "Canister 5.5.6": [
                "Ordnance 5.5.6"
            ],
            "Ordnance 5.5.6": [
                "QQ 5.5"
            ],
            "Ordnance Relay Card 5.5.7": [
                "Canister 5.5.7"
            ],
            "Canister 5.5.7": [
                "Ordnance 5.5.7"
            ],
            "Ordnance 5.5.7": [
                "QQ 5.5"
            ],
            "Ordnance Relay Card 5.5.8": [
                "Canister 5.5.8"
            ],
            "Canister 5.5.8": [
                "Ordnance 5.5.8"
            ],
            "Ordnance 5.5.8": [
                "QQ 5.5"
            ],
            "Ordnance Relay Card 5.5.9": [
                "Canister 5.5.9"
            ],
            "Canister 5.5.9": [
                "Ordnance 5.5.9"
            ],
            "Ordnance 5.5.9": [
                "QQ 5.5"
            ],
            "Ordnance Relay Card 5.5.10": [
                "Canister 5.5.10"
            ],
            "Canister 5.5.10": [
```

```
                "Ordnance 5.5.10"
            ],
            "Ordnance 5.5.10": [
                "QQ 5.5"
            ],
            "Ordnance Relay Card 5.5.11": [
                "Canister 5.5.11"
            ],
            "Canister 5.5.11": [
                "Ordnance 5.5.11"
            ],
            "Ordnance 5.5.11": [
                "QQ 5.5"
            ],
            "Ordnance Relay Card 5.5.12": [
                "Canister 5.5.12"
            ],
            "Canister 5.5.12": [
                "Ordnance 5.5.12"
            ],
            "Ordnance 5.5.12": [
                "QQ 5.5"
            ],
            "QQ 5.5": [
                "XX 5.5"
            ]
        }
    },
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",
    "Maintainer": null,
    "Maintainer Title": null,
    "Maintainer Organization": null
}
```

Listing F.10: The weapon system 6 system data file for the Reference system of systems (Weapon_System_6.sdf.json)


```
{
    "HEADER COMMENTS": "Weapon System 6 of the Reference SOS",
    "System": {
        "Weapon System 5.6": {
            "ID": "System 5.6",
            "type": "equipment",
            "subtype": "weapon",
      "color":"#00AA64",
            "VNTK": null,
            "thresholds": {
                "static overpressure": 20.61778887054905,
                "dynamic pressure": 10.308894435274524,
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                "Motor Controls 5.6": {
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                    "thresholds": {
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                "Traverse & Elevation Mechanisms 5.6": {
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                        "dynamic pressure": 6.057134749911941,
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                    "subtype": "electrical",
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                    "thresholds": {
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                        "windspeed": "inf",
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                        "PD": "inf"
                    }
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                "Elevation Motor 5.6": {
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                        "neutron fluence": 1135844234540.1377,
                        "gamma ray dose": "inf",
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                    }
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                "Processor Card Cage 5.6": {
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                        "windspeed": "inf",
                        "thermal fluence": 260.49348408975976,
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                        "neutron fluence": 1302467420448.7988,
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                        "gamma ray dose rate": 13024674204.48799,
                        "PD": "inf"
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                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
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                    "VNTK": null,
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                        "windspeed": "inf",
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                        "total dose": 802254.2750514242,
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                    "thresholds": {
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                        "windspeed": "inf",
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                        "neutron dose": "inf",
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                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 5795663112.39249,
                        "PD": "inf"
                    }
                }
            },
            "Fire Control 5.6": {
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                "type": "equipment",
                "subtype": "electrical",
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                "VNTK": null,
                "thresholds": {
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                    "dynamic pressure": 0.42599201320173086,
                    "windspeed": "inf",
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                    "neutron dose": "inf",
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                    "gamma ray dose rate": 4259920132.0173087,
                    "PD": "inf"
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                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 4.076533308042904,
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                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
                "Data Cable 5.6.1": {
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                    "type": "equipment",
                    "subtype": "mechanical",
                    "relative position": [
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                    "VNTK": null,
                    "thresholds": {
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                        "windspeed": "inf",
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                        "total dose": "inf",
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                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
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                "Data Cable 5.6.2": {
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                    "type": "equipment",
                    "subtype": "mechanical",
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                    ],
                    "VNTK": null,
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                    "thresholds": {
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                        "gamma ray dose rate": "inf",
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                    }
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                "Data Cable 5.6.3": {
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                    "subtype": "mechanical",
                    "relative position": [
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                    ],
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                    "thresholds": {
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                        "dynamic pressure": 4.978489642991361,
                        "windspeed": "inf",
                        "thermal fluence": "inf",
                        "total dose": "inf",
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                        "neutron fluence": "inf",
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": "inf",
                        "PD": "inf"
                    }
                },
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                    "VNTK": null,
                    "thresholds": {
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                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 7706117167.874542,
                        "PD": "inf"
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                    }
                },
                "Ordnance Relay Card 5.6.2": {
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                    "type": "equipment",
                    "subtype": "electrical",
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                    "thresholds": {
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                        "dynamic pressure": 1.5984208497416477,
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                        "gamma ray dose rate": 15984208497.416477,
                        "PD": "inf"
                    }
                },
                "Ordnance Relay Card 5.6.3": {
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                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
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                    "VNTK": null,
                    "thresholds": {
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                        "dynamic pressure": 1.5354974199515186,
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                        "neutron fluence": 1535497419951.5186,
                        "gamma ray dose": "inf",
                        "gamma ray dose rate": 15354974199.515186,
                        "PD": "inf"
                    }
                },
                "Ordnance Relay Card 5.6.4": {
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                    "type": "equipment",
                    "subtype": "electrical",
                    "relative position": [
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            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.6"
                    ],
                    "End Node": [
                        "PP 5.6"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Does NOT aim self"
                }
            }
        ],
        "Fires Primary Weapon Ordnance": [
            {
                "Possible": {
                    "Begin Node": [
                        "X 5.6"
                    ],
                    "End Node": [
                        "QQ 5.6"
                    ],
                    "Has Path": [
                        true
                    ],
                    "Comment": "Can fire one or more rounds of ordnance"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
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                    ],
                    "End Node": [
                        "QQ 5.6"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT fire primary weapon system"
                }
            }
        ],
        "Communicate with Command and Control System": [
            {
                "Via FO Cable or VHF Radio": {
                    "Begin Node": [
                        "X 5.6",
                        "X 5.6"
                    ],
                    "End Node": [
                        "JJ 5.6.a",
                        "JJ 5.6.b"
                    ],
```

```
                    "Has Path": [
                        true,
                        true
                    ],
                    "Comment": "Communicates with C2 via cable or radio"
                }
            },
            {
                "NOT POSSIBLE": {
                    "Begin Node": [
                        "X 5.6"
                    ],
                    "End Node": [
                        "JJ 5.6"
                    ],
                    "Has Path": [
                        false
                    ],
                    "Comment": "Can NOT communicate with C2 system"
                }
            },
            {
                "Via FO Cable ONLY": {
                    "Begin Node": [
                        "X 5.6",
                        "X 5.6"
                    ],
                    "End Node": [
                        "JJ 5.6.a",
                        "JJ 5.6.b"
                    ],
                    "Has Path": [
                        true,
                        false
                    ],
                    "Comment": "Can communicate with C2 by cable ONLY"
                }
            },
            {
                "Via VHF Radio ONLY": {
                    "Begin Node": [
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                        "X 5.6"
                    ],
                    "End Node": [
                        "JJ 5.6.a",
                        "JJ 5.6.b"
                    ],
                    "Has Path": [
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                        true
                    ],
                    "Comment": "Can communicate with C2 by radio ONLY"
                }
            }
        ]
    },
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            "OO 5.6",
            "QQ 5.6",
            "JJ 5.6",
            "JJ 5.6.a",
            "JJ 5.6.b",
            "PP 5.6"
        ],
        "Terminal Nodes": [
            "X 5.6",
            "XX 5.6"
        ],
        "Edges": {
            "X 5.6": [
                "Weapon System 5.6"
            ],
            "Weapon System 5.6": [
                "NN 5.6"
            ],
            "NN 5.6": [
                "15kW Generator Set 5.6"
            ],
            "15kW Generator Set 5.6": [
                "Generator Air Intake 5.6"
            ],
            "Generator Air Intake 5.6": [
                "Generator Fuel System 5.6"
            ],
            "Generator Fuel System 5.6": [
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            ],
            "Diesel Engine 5.6": [
                "Electric Generator 5.6"
            ],
            "Electric Generator 5.6": [
                "OO 5.6"
            ],
            "OO 5.6": [
                "Electronics System 5.6"
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            "Electronics System 5.6": [
                "AC Cabinet 5.6",
                "Data Link Terminal 5.6"
            ],
            "AC Cabinet 5.6": [
                "Heater Control 5.6",
                "Compass 5.6"
            ],
            "Heater Control 5.6": [
                "Processor Card Cage 5.6"
            ],
            "Processor Card Cage 5.6": [
                "Ordnance Executive Processor Card 5.6"
            ],
            "Ordnance Executive Processor Card 5.6": [
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                "Ordnance Interface Card 5.6"
            ],
            "Compass 5.6": [
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            ],
            "GPS Receiver 5.6": [
                "GPS Antenna 5.6"
            ],
            "GPS Antenna 5.6": [
                "Power Controls 5.6"
            ],
            "Power Controls 5.6": [
                "Motor Controls 5.6"
            ],
            "Motor Controls 5.6": [
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            ],
            "Azimuth Motor 5.6": [
                "Elevation Motor 5.6"
            ],
            "Elevation Motor 5.6": [
                "PP 5.6"
            ],
            "PP 5.6": [
                "XX 5.6"
            ],
            "Data Link Terminal 5.6": [
                "Digital Processor 5.6"
            ],
            "Digital Processor 5.6": [
                "Fiber Optic Modem 5.6",
                "VHF Radio 5.6"
            ],
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            ],
            "JJ 5.6.a": [
                "JJ 5.6"
            ],
            "JJ 5.6": [
                "XX 5.6"
            ],
            "VHF Radio 5.6": [
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            ],
            "EMP Suppressor 5.6": [
                "Radio Antenna 5.6"
            ],
            "Radio Antenna 5.6": [
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            ],
            "JJ 5.6.b": [
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            ],
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            ],
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                "Data Cable 5.6.2",
                "Data Cable 5.6.3"
            ],
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                "Ordnance Relay Card 5.6.2",
                "Ordnance Relay Card 5.6.3",
                "Ordnance Relay Card 5.6.4"
            ],
            "Data Cable 5.6.2": [
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                "Ordnance Relay Card 5.6.6",
                "Ordnance Relay Card 5.6.7",
                "Ordnance Relay Card 5.6.8"
            ],
            "Data Cable 5.6.3": [
                "Ordnance Relay Card 5.6.9",
                "Ordnance Relay Card 5.6.10",
                "Ordnance Relay Card 5.6.11",
                "Ordnance Relay Card 5.6.12"
            ],
            "Ordnance Relay Card 5.6.1": [
                "Canister 5.6.1"
            ],
            "Canister 5.6.1": [
                "Ordnance 5.6.1"
            ],
            "Ordnance 5.6.1": [
                "QQ 5.6"
            ],
            "Ordnance Relay Card 5.6.2": [
                "Canister 5.6.2"
            ],
            "Canister 5.6.2": [
                "Ordnance 5.6.2"
            ],
            "Ordnance 5.6.2": [
                "QQ 5.6"
            ],
            "Ordnance Relay Card 5.6.3": [
                "Canister 5.6.3"
            ],
            "Canister 5.6.3": [
                "Ordnance 5.6.3"
            ],
            "Ordnance 5.6.3": [
                "QQ 5.6"
            ],
            "Ordnance Relay Card 5.6.4": [
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                "Canister 5.6.4"
            ],
            "Canister 5.6.4": [
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            ],
            "Ordnance 5.6.4": [
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            ],
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            ],
            "Canister 5.6.5": [
                "Ordnance 5.6.5"
            ],
            "Ordnance 5.6.5": [
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            ],
            "Ordnance Relay Card 5.6.6": [
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            ],
            "Canister 5.6.6": [
                "Ordnance 5.6.6"
            ],
            "Ordnance 5.6.6": [
                "QQ 5.6"
            ],
            "Ordnance Relay Card 5.6.7": [
                "Canister 5.6.7"
            ],
            "Canister 5.6.7": [
                "Ordnance 5.6.7"
            ],
            "Ordnance 5.6.7": [
                "QQ 5.6"
            ],
            "Ordnance Relay Card 5.6.8": [
                "Canister 5.6.8"
            ],
            "Canister 5.6.8": [
                "Ordnance 5.6.8"
            ],
            "Ordnance 5.6.8": [
                "QQ 5.6"
            ],
            "Ordnance Relay Card 5.6.9": [
                "Canister 5.6.9"
            ],
            "Canister 5.6.9": [
                "Ordnance 5.6.9"
            ],
            "Ordnance 5.6.9": [
                "QQ 5.6"
            ],
            "Ordnance Relay Card 5.6.10": [
                "Canister 5.6.10"
            ],
            "Canister 5.6.10": [
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                "Ordnance 5.6.10"
            ],
            "Ordnance 5.6.10": [
                "QQ 5.6"
            ],
            "Ordnance Relay Card 5.6.11": [
                "Canister 5.6.11"
            ],
            "Canister 5.6.11": [
                "Ordnance 5.6.11"
            ],
            "Ordnance 5.6.11": [
                "QQ 5.6"
            ],
            "Ordnance Relay Card 5.6.12": [
                "Canister 5.6.12"
            ],
            "Canister 5.6.12": [
                "Ordnance 5.6.12"
            ],
            "Ordnance 5.6.12": [
                "QQ 5.6"
            ],
            "QQ 5.6": [
                "XX 5.6"
            ]
        }
    },
    "Developer Name": "R. Boone Gilbreath",
    "Developer Title": "Major, U.S. Army",
    "Developer Organization": "Radiation Transport Applications Group, Los Alamos National Laboratory",
    "Maintainer": null,
    "Maintainer Title": null,
    "Maintainer Organization": null
}
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F.3.3 Scenario Data Files

Listing F.11: The Volunteer Plasma analytical scenario data file (Volunteer_Plasma.scdf.json)

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  "Prefix":"C:\\Users\\339528\\Documents\\Git\\NuSCAP\\Users\\Gilbreath\\Scenarios\\",
  "Name":"Volunteer_Plasma",
    "MCNP path":"C:\\MCNP62\\MCNP_CODE\\bin\\mcnp6",
    "MCNP datapath":"C:\\MCNP62\\MCNP_DATA",
    "MCNP threads":8,
    "SNEC path":"C:\\Users\\339528\\Documents\\Git\\NuSCAP\\NuSCAP\\JSL\\JSL_5.6\\Dist_2\\Combined_JSL_5
     .6_Distro\\Java Tools for Windows\\WebMultipleEffects",
    "GIS and Weather Data":{
        "GIS Reference Datum": "WGS84",
        "Ground Zero Location": "13S CT 63233 27353",
        "Ground Zero Elevation (MSL) [m]": 1501,
        "DTG":"31 1000S JUL 2023",
        "Atmospheric Visibility [km]": 16
    },
    "Threat Weapon Data":{
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        "Fission Fraction": 1,
        "Yield [kt]": 10.0,
        "HOB [m]": 139,
        "HOB sigma [m]":0,
        "CEP [m]": 0,
        "NPS":5E5,
        "Neutron Leakage Spectrum":{
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            "si option":"H",
            "energy bins [MeV]":[
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                3.00E-8, 4.00E-8, 5.00E-8, 7.00E-8, 1.00E-7, 1.25E-7, 1.50E-7, 1.84E-7,
                2.25E-7, 2.75E-7, 3.25E-7, 3.67E-7, 4.14E-7, 5.00E-7, 5.32E-7, 6.25E-7,
                6.83E-7, 8.00E-7, 8.67E-7, 1.00E-6, 1.04E-6, 1.08E-6, 1.13E-6, 1.30E-6,
                1.45E-6, 1.86E-6, 2.38E-6, 3.06E-6, 3.93E-6, 5.04E-6, 6.48E-6, 8.32E-6,
                1.07E-5, 1.37E-5, 1.76E-5, 2.26E-5, 2.90E-5, 3.73E-5, 4.79E-5, 6.14E-5,
                7.89E-5, 1.01E-4, 1.30E-4, 1.67E-4, 2.14E-4, 2.75E-4, 3.54E-4, 4.54E-4,
                5.83E-4, 7.49E-4, 9.61E-4, 1.23E-3, 1.58E-3, 2.03E-3, 2.25E-3, 2.49E-3,
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                9.12E-3, 1.06E-2, 1.17E-2, 1.50E-2, 1.93E-2, 2.19E-2, 2.36E-2, 2.42E-2,
                2.48E-2, 2.61E-2, 2.70E-2, 2.85E-2, 3.18E-2, 3.43E-2, 4.09E-2, 4.63E-2,
                5.25E-2, 5.66E-2, 6.74E-2, 7.20E-2, 7.95E-2, 8.25E-2, 8.65E-2, 9.80E-2,
                1.11E-1, 1.17E-1, 1.23E-1, 1.29E-1, 1.36E-1, 1.43E-1, 1.50E-1, 1.58E-1,
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                2.47E-1, 2.73E-1, 2.87E-1, 2.95E-1, 2.97E-1, 2.98E-1, 3.02E-1, 3.34E-1,
                3.69E-1, 3.88E-1, 4.08E-1, 4.50E-1, 4.98E-1, 5.23E-1, 5.50E-1, 5.78E-1,
                6.08E-1, 6.39E-1, 6.72E-1, 7.07E-1, 7.43E-1, 7.81E-1, 8.21E-1, 8.63E-1,
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                2.59, 2.73, 2.87, 3.01, 3.17, 3.33, 3.68, 4.07, 4.49, 4.72, 4.97, 5.23,
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                748, 886, 1.04E3, 1.19E3, 1.34E3, 1.45E3, 1.52E3, 1.54E3, 1.48E3, 1.36E3,
                1.19E3, 996, 794, 614, 462, 334, 228, 141, 74.8, 33.3, 12.4, 3.84, 1.02,
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                4.53E-3, 4.36E-3, 4.87E-3, 4.89E-3, 1.20E-3, 1.42E-3, 1.31E-3, 1.13E-3, 1.92E-3,
                1.76E-3, 1.65E-3, 1.79E-3, 2.17E-3, 1.70E-3, 1.30E-3, 5.97E-4, 8.85E-4, 1.16E-3,
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                7.30E-4, 8.21E-4, 6.02E-4, 7.36E-4, 6.93E-4, 7.46E-4, 6.05E-4, 6.61E-4, 4.35E-4,
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                1.29E-6, 9.17E-7, 3.68E-7, 4.17E-7, 1.96E-7, 8.11E-8, 2.01E-7, 1.63E-7, 2.43E-7,
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            "reference":"R. Holmes and S. White, 'Output of Fat Man and Little Boy Devices,' Los Alamos
    National Laboratory, LA-UR-13-26113, Aug. 2103; Tables 2 & 6"
        },
        "Neutron Response Functions":{
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                "Energy [MeV]":[
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                    7.0, 10.0, 14.0, 20.0
                ],
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                    "values":
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                    1.32E-4, 1.25E-4, 1.56E-4, 1.47E-4, 1.47E-4, 2.08E-4, 2.27E-4
                    ]
                    },
                "Quality Factor":[
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                ],
                "reference":"J. Kulesza, et al., 'MCNP Code Version 6.3.0 Theory & User Manual,' Los
    Alamos National Laboratory, Los Alamos, NM, USA, Tech. Rep. LA-UR-22-30006, Rev. 1, Sep. 2022. ANSI/
    ANS-6.1.1-1977, Table 1"
            },
            "Equipment":{
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                        1.00000E-07, 1.52300E-07, 2.00000E-07, 4.13990E-07, 6.00000E-07, 8.00000E-07,
                        1.12530E-06, 3.05900E-06, 5.04350E-06, 8.31530E-06, 1.37100E-05, 2.26030E-05,
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                        8.65170E-02, 1.11090E-01, 1.42640E-01, 1.83160E-01, 2.35180E-01, 3.01970E-01,
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                        8.20850E-01, 9.30140E-01, 1.05400E00, 1.19430E00, 1.35340E00, 1.73770E00,
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                        "values":
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                        5.52298E-04, 4.53680E-04, 3.83152E-04, 2.93933E-04, 2.26408E-04, 1.92229E-04,
                        1.64111E-04, 1.14214E-04, 8.03363E-05, 6.25425E-05, 4.87135E-05, 3.79357E-05,
                        2.95522E-05, 2.30102E-05, 1.79240E-05, 1.39594E-05, 3.00309E-04, 5.55850E-04,
                        6.65494E-04, 7.68969E-04, 9.10440E-04, 1.10621E-03, 1.29490E-03, 1.44634E-03,
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            },
            "Notes":"R. Detwiler, et al., 'Compendium of Material Composition Data for Radiation Transport Modeling,' Pacific Northwest National Laboratory, Richland, WA PNNL-15870, Rev. 2, Apr. 2021; Table 116; O-18 neglected to permit ENDF/B-VII use"
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    "Developer Title":"Major, U.S. Army",
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Listing F.12: The Volunteer Tan analytical scenario data file (Volunteer_Tan.scdf.json)


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                "25055":-0.000715,
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            "Notes":"R. Detwiler, et al., 'Compendium of Material Composition Data for Radiation Transport Modeling,' Pacific Northwest National Laboratory, Richland, WA PNNL-15870, Rev. 2, Apr. 2021; Table 116; O-18 neglected to permit ENDF/B-VII use"
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    "Developer Title":"Major, U.S. Army",
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Listing F.13: The Volunteer Sunrise analytical scenario data file (Volunteer_Sunrise.scdf.json)

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                        1.64111E-04, 1.14214E-04, 8.03363E-05, 6.25425E-05, 4.87135E-05, 3.79357E-05,
                        2.95522E-05, 2.30102E-05, 1.79240E-05, 1.39594E-05, 3.00309E-04, 5.55850E-04,
                        6.65494E-04, 7.68969E-04, 9.10440E-04, 1.10621E-03, 1.29490E-03, 1.44634E-03,
                        1.60935E-03, 1.80074E-03, 2.01916E-03, 2.27304E-03, 3.26010E-03, 2.87101E-03,
                        3.21528E-03, 3.61954E-03, 4.06547E-03, 4.58726E-03, 5.22228E-03, 5.83754E-03,
                        6.49984E-03, 7.30252E-03, 8.18355E-03, 9.18417E-03, 1.02944E-02, 1.15055E-02,
                        1.28715E-02, 1.43322E-02, 1.63567E-02, 1.77608E-02, 1.96045E-02, 2.16808E-02,
                        2.30574E-02, 2.40674E-02, 2.58766E-02, 2.95862E-02, 2.53388E-02, 1.44824E-01,
                        6.03347E-02, 4.99138E-02, 2.51383E-02, 3.30996E-01, 9.39793E-01, 5.87161E-01,
                        5.27088E-01, 5.51634E-01, 5.74569E-01, 8.18293E-01, 6.84671E-01, 5.99507E-01,
                        9.58147E-01, 1.02449E+00, 1.02066E+00, 7.14611E-01, 9.53149E-01, 1.23834E+00,
                        1.18819E+00, 1.24346E+00, 1.21600E+00, 1.44917E+00, 1.66224E+00, 1.69987E+00,
                        1.80733E+00, 1.79803E+00, 1.88335E+00, 1.88105E+00, 1.94630E+00, 2.04731E+00
                        ]
                    },
                    "reference":"K. R. DePriest, 'Silicon Damage Response Function Derivation and
    Verification: Assessment of Impact on ASTM Standard E722,' Sandia National Laboratories, SAND2016
    -5511, Jun. 2016; Appendix B"
                },
                "Dose":{
                "units":"[rad (Si)]",
                "values":"3.3450364E-10  3  -4  1",
                "reference":"MatMCNP, K. R. DePriest"
     }
       }
       },
       "Photon Leakage Spectrum":{
           "photon yield [mol/kt]":9.02E-2,
           "si option":"H",
           "energy bins [MeV]":[
               0.001, 0.010, 0.020, 0.030, 0.040, 0.045, 0.060, 0.070, 0.075, 0.100, 0.150,
               0.200, 0.300, 0.400, 0.450, 0.510, 0.512, 0.600, 0.700, 0.800, 1.000, 1.330,
               1.340, 1.500, 1.660, 2.000, 2.500, 3.000, 3.500, 4.000, 4.500, 5.000, 5.500,
               6.000, 6.500, 7.000, 7.500, 8.000, 10.000, 12.000, 14.000, 20.000, 30.000
           ],
           "sp option":"D",
           "probability [mol/MeV-kt]":[
               0, 4.43E-4, 8.51E-4, 7.53E-4, 1.39E-3, 2.25E-3, 5.86E-3, 1.72E-2, 2.38E-2,
               5.85E-2, 8.00E-2, 7.46E-2, 7.76E-2, 5.83E-2, 5.48E-2, 6.76E-2, 3.85E-1, 7.32E-2,
               4.00E-2, 3.35E-2, 3.08E-2, 2.34E-2, 1.90E-2, 2.07E-2, 1.84E-2, 1.66E-2, 1.59E-2,
               7.66E-3, 4.25E-3, 5.43E-3, 2.58E-3, 6.75E-4, 5.44E-4, 4.29E-4, 3.55E-4, 3.50E-4,
               1.20E-4, 9.42E-4, 2.79E-5, 9.69E-6, 3.38E-8, 1.67E-13, 0
           ],
           "reference":"R. Holmes and S. White, 'Output of Fat Man and Little Boy Devices,' Los Alamos
    National Laboratory, LA-UR-13-26113, Aug. 2103; Tables 2 & 7"
```

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        },
        "Photon Response Functions":{
            "Human":{
            "Energy [MeV]":[
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                0.65, 0.7, 0.8, 1.0, 1.4, 1.8, 2.2, 2.6, 2.8, 3.25, 3.75, 4.25, 4.75, 5.0, 5.25,
                5.75, 6.25, 6.75, 7.5, 9.0, 11.0, 13.0, 15.0
            ],
            "Conversion Factor":{
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                "values":
                [
                3.96E-6, 5.82E-7, 2.9E-7, 2.58E-7, 2.83E-7, 3.79E-7, 5.01E-7, 6.31E-7, 7.59E-7,
                8.78E-7, 9.85E-7, 1.08E-6, 1.11E-6, 1.27E-6, 1.36E-6, 1.44E-6, 1.52E-6, 1.68E-6,
                1.98E-6, 2.51E-6, 2.99E-6, 3.42E-6, 3.82E-6, 4.01E-6, 4.41E-6, 4.83E-6, 5.23E-6,
                5.6E-6, 5.8E-6, 6.01E-6, 6.37E-6, 6.74E-6, 7.11E-6, 7.66E-6, 8.77E-6, 1.03E-5,
                1.18E-5, 1.33E-5
                ]
            },
            "reference":"J. Kulesza, et al.,’MCNP Code Version 6.3.0 Theory & User Manual,’ Los Alamos
    National Laboratory, Los Alamos, NM, USA, Tech. Rep. LA-UR-22-30006, Rev. 1, Sep. 2022. ANSI/ANS
    -6.1.1-1977, Table 3"
            },
            "Equipment":{
    "units":"[rad (Si)]",
    "values":"3.4350364E-10  3  -5  -6",
    "reference":"MatMCNP, K. R. DePriest"
      }
        }
    },
    "Systems Data":{

        "Command & Control":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63233 27345",
            "Elevation (MSL) [m]": 1501,
                  "R95 [km]": 0,
                  "Depth [m]":0,
            "Heading [grid deg]": 0
            }
        },
        "Electric Power Plant":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63243 27353",
            "Elevation (MSL) [m]": 1501,
                  "R95 [km]": 0,
                  "Depth [m]":0,
            "Heading [grid deg]": 0
            }
        },
        "Target Sensor":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63233 27363",
            "Elevation (MSL) [m]": 1501,
                  "R95 [km]": 0,
                  "Depth [m]":0,
            "Heading [grid deg]": 0
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            }
        },
        "Weapon System 5.1":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 62644 28166",
            "Elevation (MSL) [m]": 1492,
                  "R95 [km]": 0,
                  "Depth [m]":0,
            "Heading [grid deg]": 340
            }
        },
        "Weapon System 5.2":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 62884 27926",
            "Elevation (MSL) [m]": 1496,
                  "R95 [km]": 0,
                  "Depth [m]":0,
            "Heading [grid deg]": 350
            }
        },
        "Weapon System 5.3":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63124 28166",
            "Elevation (MSL) [m]": 1501,
                  "R95 [km]": 0,
                  "Depth [m]":0,
            "Heading [grid deg]": 0
            }
        },
        "Weapon System 5.4":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63364 28166",
            "Elevation (MSL) [m]": 1507,
                  "R95 [km]": 0,
                  "Depth [m]":0,
            "Heading [grid deg]": 0
            }
        },
        "Weapon System 5.5":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63604 27926",
            "Elevation (MSL) [m]": 1511,
                  "R95 [km]": 0,
                  "Depth [m]":0,
            "Heading [grid deg]": 10
            }
        },
        "Weapon System 5.6":{
          "GIS Data":{
            "Location (MGRS)": "13S CT 63844 28166",
            "Elevation (MSL) [m]": 1518,
                  "R95 [km]": 0,
                  "Depth [m]":0,
            "Heading [grid deg]": 20
            }
        }
    },
```

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    "Transport Materials":{
        "Surface":{
            "Name":"Earth, U.S. Average",
            "Density [g/cm^3]":1.52,
            "Composition":{
                "8016":-0.512323,
                "8017":-0.000207,
                "11023":-0.006140,
                "12000":-0.013304,
                "13027":-0.068564,
                "14000":-0.271180,
                "19000":-0.014327,
                "20000":-0.051166,
                "22000":-0.004604,
                "25055":-0.000715,
                "26000":-0.056285
            },
            "Notes":"R. Detwiler, et al., 'Compendium of Material Composition Data for Radiation Transport Modeling,' Pacific Northwest National Laboratory, Richland, WA PNNL-15870, Rev. 2, Apr. 2021; Table 116; O-18 neglected to permit ENDF/B-VII use"
        },
        "Atmosphere":{
            "Name":"Air (dry, near sea level)",
            "Density [g/cm^3]":0.001205,
            "Composition":{
                "6000":-0.000124,
                "7014":-0.752316,
                "7015":-0.002944,
                "8016":-0.231153,
                "8017":-0.000094,
                "18000":-0.012827
            },
            "Notes":"R. Detwiler, et al., 'Compendium of Material Composition Data for Radiation Transport Modeling,' Pacific Northwest National Laboratory, Richland, WA PNNL-15870, Rev. 2, Apr. 2021; Table 4; O-18 neglected to permit ENDF/B-VII use"
        },
        "Detector":{

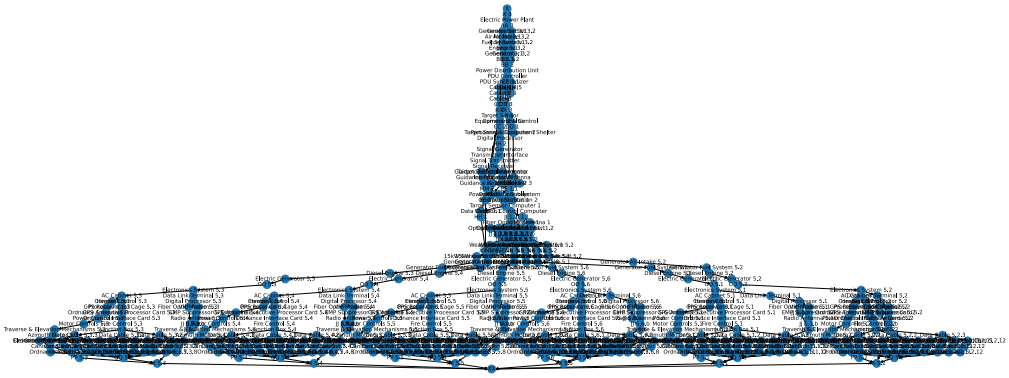
            "Name":"Silicon",
            "Density [g/cm^3]":2.33,
            "Composition":{
                "14028":0.92223,
                "14029":0.04685,
                "14030":0.03092
            },
            "Notes":"Nuclear Wallet Cards - Electronic Version, provided by K. R. DePriest"
        }
    },

    "Developer Name":"R. Boone Gilbreath",
    "Developer Title":"Major, U.S. Army",
    "Developer Organization":"Radiation Transport Applications Group, Los Alamos National Laboratory",

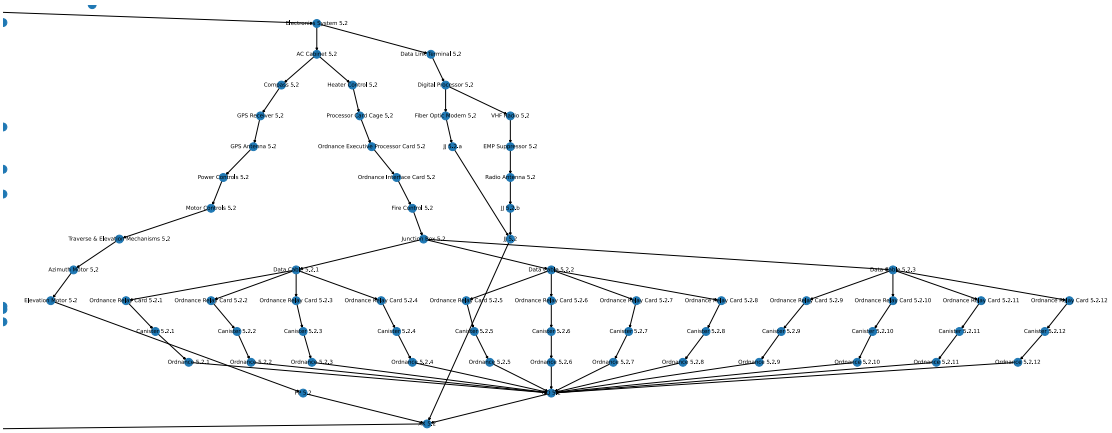
    "Maintainer":null,
    "Maintainer Title":null,
    "Maintainer Organization":null
}
```

F.4 NuSCAP Output Files

NuSCAP output reports along with post-detonation SOS graphs for each case study scenario are provided here. The SOS-level output file for each scenario ends in "`Reference.out.json`," individual system-level reports are named according to the detailed system. The universal pre-detonation SOS graph for all three scenarios is shown in figure F.6.



(a) The entire Reference SOS graph.



(b) A close-in view of the Reference SOS graph showing detail retained in the region of Weapon System 2.

Figure F.6: The Reference SOS graph for all three case study scenarios.

F.4.1 Volunteer Plasma

F.4.1.1 NuSCAP Reports

Listing F.14: The Reference system-of-system report for the Volunteer Plasma scenario (20230706_211123_Reference.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality and residual capabilities of Reference during Volunteer_Plasma. Causes of dysfunction for constitutent systems are also reported.",
    "DTG of Report": "06 2111 July 2023",
    "Reference": {
        "SOS Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Prime Systems": {
                "Maximum Capability": "Can NOT power Command & Control or Target Sensor system",
                "Capability States": {
                    "Powers C2 & Target Sensor": false,
                    "NOT POSSIBLE": true,
                    "Powers Target Sensor system ONLY": false,
                    "Powers Command & Control system ONLY": false
                }
            },
            "Control Electric Power Plant": {
                "Maximum Capability": "Can NOT control Electric Power Plant",
                "Capability States": {
                    "Remote and Local Control Possible": false,
                    "NOT POSSIBLE 1": true,
                    "NOT POSSIBLE 2": false,
                    "Local Control": false
                }
            },
            "Acquire Targets": {
                "Maximum Capability": "Target Sensor can NOT sense or identify targets",
                "Capability States": {
                    "Senses and Identifies Targets": false,
                    "NOT POSSIBLE 1": true,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "NOT POSSIBLE 4": false,
                    "NOT POSSIBLE 5": false,
                    "Senses Targets ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.1": {
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": true,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.2": {
```

```
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": true,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.3": {
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": true,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.4": {
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": true,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.5": {
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": true,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.6": {
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": true,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            }
        },
        "Command & Control": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Target Sensor": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Electric Power Plant": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Weapon System 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Weapon System 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Weapon System 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Weapon System 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Weapon System 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Weapon System 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        }
    }
}
```

Listing F.15: The command and control system report for the Volunteer Plasma scenario (20230706_211123_Command & Control.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Command & Control and its subordinate elements during Volunteer_Plasma.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 2111 July 2023",
    "Command & Control": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Protect Personnel and Eqipment": {
                "Maximum Capability": "Does NOT protect personnel and eqipment",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Control Mobile Power Plant Remotely": {
                "Maximum Capability": "Remote control of Mobile Power Plant NOT possible",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Control Target Sensor Remotely": {
                "Maximum Capability": "Remote control of Target Sensor NOT possible",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Control Weapon System 1": {
                "Maximum Capability": "Can NOT control Weapon Station 1",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 2": {
                "Maximum Capability": "Can NOT control Weapon Station 1",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 3": {
                "Maximum Capability": "Can NOT control Weapon Station 1",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
```

```
            },
            "Control Weapon System 4": {
                "Maximum Capability": "Can NOT control Weapon Station 1",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 5": {
                "Maximum Capability": "Can NOT control Weapon Station 1",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 6": {
                "Maximum Capability": "Can NOT control Weapon Station 1",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Command & Control": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Personnel & Equipment Shelter": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Operations Subsystem": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Soldier 1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "total dose",
```

```
                "PD"
            ]
        },
        "Soldier 2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "total dose",
                "PD"
            ]
        },
        "Soldier 3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "total dose",
                "PD"
            ]
        },
        "Power Plant Controller": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Operator Station 1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Operator Station 2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Target Sensor Computer 1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Data Cable 1.1": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "total dose"
            ]
        },
        "Weapon Control Computer": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "VHF Antenna 1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Fiber Optic Modem 1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Optical Fiber 1.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Optical Fiber 1.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Optical Fiber 1.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Optical Fiber 1.4": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Optical Fiber 1.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Optical Fiber 1.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        }
    }
}
```

Listing F.16: The target sensor system report for the Volunteer Plasma scenario (20230706_211123_Target Sensor.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Target Sensor and its subordinate elements during Volunteer_Plasma.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 2111 July 2023",
    "Target Sensor": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Protect Equipment": {
                "Maximum Capability": "Does NOT provide equipment ballistic and environmental protection",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with C2": {
                "Maximum Capability": "Can NOT receive and transmit dat with C2",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Detect Targets": {
                "Maximum Capability": "Can NOT detect or classify targets",
                "Capability States": {
                    "Detects and classifies targets": false,
                    "NOT POSSIBLE": true,
                    "Detects targets ONLY": false
                }
            },
            "Guide Ordnance": {
                "Maximum Capability": "Can NOT communicate guidance data to ordnance",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            }
        },
        "Target Sensor": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Equipment Shelter": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Target Sensor Computer 2": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Digital Processor": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Signal Generator": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Transmitter Interface": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Signal Transmitter": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Signal Receiver": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Target Interrogator": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
```

```
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Interrogator Antenna": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Guidance Correlator": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Guidance Processor": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Guidance Antenna": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Target Detection Antenna": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        }
    }
}
```

Listing F.17: The electric power plant system report for the Volunteer Plasma scenario (20230706_211123_Electric Power Plant.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Electric Power Plant and its subordinate elements during Volunteer_Plasma.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 2111 July 2023",
    "Electric Power Plant": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Generate Electrical Power": {
                "Maximum Capability": "Electrical power generation NOT possible",
                "Capability States": {
                    "Via Generator Set 1 and Generator Set 2": false,
                    "NOT POSSIBLE": true,
                    "Via Generator Set 1 or Generator Set 2": false
                }
            },
            "Power Prime Loads": {
                "Maximum Capability": "Can NOT power any prime loads",
                "Capability States": {
                    "Powers C2 and Target Sensor": false,
                    "NOT POSSIBLE": true,
                    "Powers C2 ONLY": false,
                    "Powers Target Sensor ONLY": false
                }
            },
            "Communicate with C2": {
                "Maximum Capability": "Communication with C2 NOT possible",
                "Capability States": {
                    "Via Remote Control and Local Panel": false,
                    "NOT POSSIBLE": true,
                    "Via Local Panel ONLY": false
                }
            }
        },
        "Electric Power Plant": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Generator Set 3.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Generator Set 3.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
```

```
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Power Distribution Unit": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Air Intake 3.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fuel System 3.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Engine 3.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Generator 3.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Air Intake 3.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fuel System 3.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
```

```
        "Engine 3.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Generator 3.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "PDU Controller": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "PDU Synchronizer": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence",
                "gamma ray dose rate"
            ]
        },
        "Cable J1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Cable J2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Cable J3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Cable J4": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Cable J5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        }
    }
}
```

Listing F.18: The weapon system 1 report for the Volunteer Plasma scenario (20230706_211123_Weapon System 5.1.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.1 and its subordinate elements during Volunteer_Plasma.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 2111 July 2023",
    "Weapon System 5.1": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Electronics System 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Fire Control 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Air Intake 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "VHF Radio 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EMP Suppressor 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Radio Antenna 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Compass 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
```

```
                "dynamic pressure"
            ]
        },
        "GPS Receiver 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Antenna 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Power Controls 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Motor Controls 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Traverse & Elevation Mechanisms 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Processor Card Cage 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Executive Processor Card 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Interface Card 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Junction Box 5.1": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.1.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Ordnance Relay Card 5.1.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Ordnance 5.1.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.1.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.19: The weapon system 2 report for the Volunteer Plasma scenario (20230706_211123_Weapon System 5.2.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.2 and its subordinate elements during Volunteer_Plasma.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 2111 July 2023",
    "Weapon System 5.2": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Electronics System 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
```

```
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fire Control 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Generator Air Intake 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "AC Cabinet 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Digital Processor 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fiber Optic Modem 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "VHF Radio 5.2": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "EMP Suppressor 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Radio Antenna 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed"
            ]
        },
        "Compass 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "GPS Receiver 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "GPS Antenna 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed"
            ]
        },
        "Power Controls 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Motor Controls 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Traverse & Elevation Mechanisms 5.2": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Elevation Motor 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Heater Control 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Processor Card Cage 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Executive Processor Card 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Interface Card 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Junction Box 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Data Cable 5.2.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.2.2": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.2.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.8": {
```

```
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.11": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Canister 5.2.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
```

```
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Canister 5.2.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.2.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.2.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.2.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.2.5": {
```

```
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.2.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.2.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.2.8": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.2.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.2.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.2.11": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.2.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        }
    }
}
```

Listing F.20: The weapon system 3 report for the Volunteer Plasma scenario (20230706_211123_Weapon System 5.3.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.3 and its subordinate elements during Volunteer_Plasma.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 2111 July 2023",
    "Weapon System 5.3": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Electronics System 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Fire Control 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Generator Air Intake 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "AC Cabinet 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Digital Processor 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fiber Optic Modem 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "VHF Radio 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "EMP Suppressor 5.3": {
```

```
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Radio Antenna 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Compass 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "GPS Receiver 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "GPS Antenna 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Power Controls 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Motor Controls 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Traverse & Elevation Mechanisms 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Elevation Motor 5.3": {
```

```
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Heater Control 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Processor Card Cage 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Executive Processor Card 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Interface Card 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Junction Box 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.3.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.2": {
```

```
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.8": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
```

```
        },
        "Ordnance Relay Card 5.3.11": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Canister 5.3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.11": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.3.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.8": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Ordnance 5.3.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.21: The weapon system 4 report for the Volunteer Plasma scenario (20230706_211123_Weapon System 5.4.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.4 and its subordinate elements during Volunteer_Plasma.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 2111 July 2023",
    "Weapon System 5.4": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Electronics System 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
```

```
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fire Control 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Generator Air Intake 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "AC Cabinet 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Digital Processor 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fiber Optic Modem 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "VHF Radio 5.4": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "EMP Suppressor 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Radio Antenna 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed"
            ]
        },
        "Compass 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "GPS Receiver 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "GPS Antenna 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed"
            ]
        },
        "Power Controls 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Motor Controls 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Traverse & Elevation Mechanisms 5.4": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Elevation Motor 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Heater Control 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Processor Card Cage 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Executive Processor Card 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Interface Card 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Junction Box 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.4.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.4.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.4.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.1": {
```

```
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.4.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.4.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.4.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.4.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.4.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.4.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.4.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
```

```
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.4.11": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.4.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Canister 5.4.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Canister 5.4.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.4.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.4.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.4.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.4.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.4.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.4.10": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.11": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.4.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.22: The weapon system 5 report for the Volunteer Plasma scenario (20230706_211123_Weapon System 5.5.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.5 and its subordinate elements during Volunteer_Plasma.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 2111 July 2023",
    "Weapon System 5.5": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Electronics System 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
```

```
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fire Control 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Generator Air Intake 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Electric Generator 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "AC Cabinet 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Digital Processor 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fiber Optic Modem 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
```

```
        "VHF Radio 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "EMP Suppressor 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Radio Antenna 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed"
            ]
        },
        "Compass 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "GPS Receiver 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "GPS Antenna 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed"
            ]
        },
        "Power Controls 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Motor Controls 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
```

```
        },
        "Traverse & Elevation Mechanisms 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Elevation Motor 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Heater Control 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Processor Card Cage 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Executive Processor Card 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Interface Card 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Junction Box 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
```

```
        },
        "Data Cable 5.5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.5.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
```

```
        },
        "Ordnance Relay Card 5.5.8": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.5.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.5.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.5.11": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.5.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Canister 5.5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.6": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.5.5": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.5.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.5.8": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.5.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.5.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.5.11": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.5.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        }
    }
}
```

Listing F.23: The weapon system 6 report for the Volunteer Plasma scenario (20230706_211123_Weapon System 5.6.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.6 and its subordinate elements during Volunteer_Plasma.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 2111 July 2023",
    "Weapon System 5.6": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Electronics System 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
```

```
                "dynamic pressure"
            ]
        },
        "Fire Control 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Generator Air Intake 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Radio 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EMP Suppressor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Radio Antenna 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Compass 5.6": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Receiver 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Antenna 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Power Controls 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Motor Controls 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Traverse & Elevation Mechanisms 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Processor Card Cage 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Executive Processor Card 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Interface Card 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Junction Box 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.6.1": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.6.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.6.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance Relay Card 5.6.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.8": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance Relay Card 5.6.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.11": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
```

```
                "static overpressure"
            ]
        },
        "Ordnance 5.6.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.6.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        }
    }
}
```

F.4.1.2 SOS Graph

Figure F.7 shows the altered SOS graph following NuSCAP analysis during the Volunteer Plasma scenario. Black nodes with white text denote dysfunctional nodes. Edges removed from the computational graph are shown in pale gray to provide context.

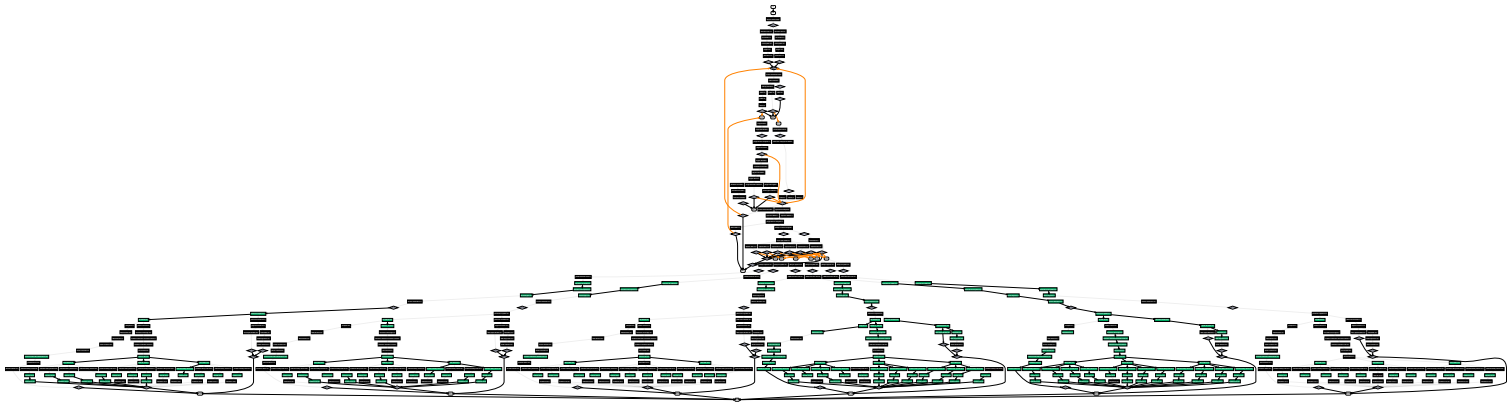


Figure F.7: Post-analysis SOS graph for the Volunteer Plasma scenario.

F.4.2 Volunteer Tan

F.4.2.1 NuSCAP Reports

Listing F.24: The Reference system-of-system report for the Volunteer Tan scenario (20230706_182029_Reference.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality and residual capabilities of Reference during Volunteer_Tan. Causes of dysfunction for constitutent systems are also reported.",
    "DTG of Report": "06 1820 July 2023",
    "Reference": {
        "SOS Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Prime Systems": {
                "Maximum Capability": "Powers Command & Control and Target Sensor systems",
                "Capability States": {
                    "Powers C2 & Target Sensor": true,
                    "NOT POSSIBLE": false,
                    "Powers Target Sensor system ONLY": false,
                    "Powers Command & Control system ONLY": false
                }
            },
            "Control Electric Power Plant": {
                "Maximum Capability": "Electric Power Plant control available by remote and local control panel",
                "Capability States": {
                    "Remote and Local Control Possible": true,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": false,
                    "Local Control": false
                }
            },
            "Acquire Targets": {
                "Maximum Capability": "Target Sensor can NOT sense or identify targets",
                "Capability States": {
                    "Senses and Identifies Targets": false,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": true,
                    "NOT POSSIBLE 4": false,
                    "NOT POSSIBLE 5": false,
                    "Senses Targets ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.1": {
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": true,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
```

```
            "Fire Ordnance from Weapon System 5.2": {
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": true,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.3": {
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": true,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.4": {
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": true,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.5": {
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": true,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.6": {
                "Maximum Capability": "Can NOT fire ordnance",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": true,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            }
        },
        "Command & Control": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Target Sensor": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Power Plant": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Weapon System 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Weapon System 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Weapon System 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Weapon System 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Weapon System 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Weapon System 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        }
    }
}
```

Listing F.25: The command and control system report for the Volunteer Tan scenario (20230706_182029_Command & Control.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Command & Control and its subordinate elements during Volunteer_Tan.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1820 July 2023",
    "Command & Control": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "Protect Personnel and Eqipment": {
                "Maximum Capability": "Protects Personnel and Eqipment",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Control Mobile Power Plant Remotely": {
                "Maximum Capability": "Remote control of Mobile Power Plant possible",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Control Target Sensor Remotely": {
                "Maximum Capability": "Remote control of Target Sensor possible",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Control Weapon System 1": {
                "Maximum Capability": "Can control Weapon System 1 by cable ONLY",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": true,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 2": {
                "Maximum Capability": "Can control Weapon System 1 by cable ONLY",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": true,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 3": {
                "Maximum Capability": "Can control Weapon System 1 by cable ONLY",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": true,
                    "Via VHF Radio ONLY": false
                }
            },
```

```
            "Control Weapon System 4": {
                "Maximum Capability": "Can control Weapon System 1 by cable ONLY",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": true,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 5": {
                "Maximum Capability": "Can control Weapon System 1 by cable ONLY",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": true,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 6": {
                "Maximum Capability": "Can control Weapon System 1 by cable ONLY",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": true,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Command & Control": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Personnel & Equipment Shelter": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Operations Subsystem": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Soldier 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Soldier 2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Soldier 3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Power Plant Controller": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Operator Station 1": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Operator Station 2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Target Sensor Computer 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Weapon Control Computer": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Antenna 1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Fiber Optic Modem 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.26: The target sensor system report for the Volunteer Tan scenario (20230706_182029_Target Sensor.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Target Sensor and its subordinate elements during Volunteer_Tan.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1820 July 2023",
    "Target Sensor": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Protect Equipment": {
                "Maximum Capability": "Provides equipment ballistic and environmental protection",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Communicate with C2": {
                "Maximum Capability": "Receives and transmits data with C2",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Detect Targets": {
                "Maximum Capability": "Can NOT detect or classify targets",
                "Capability States": {
                    "Detects and classifies targets": false,
                    "NOT POSSIBLE": true,
                    "Detects targets ONLY": false
                }
            },
            "Guide Ordnance": {
                "Maximum Capability": "Can NOT communicate guidance data to ordnance",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            }
        },
        "Target Sensor": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Equipment Shelter": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Target Sensor Computer 2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Signal Generator": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Transmitter Interface": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Signal Transmitter": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Signal Receiver": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Target Interrogator": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Interrogator Antenna": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Guidance Correlator": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Guidance Processor": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Guidance Antenna": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Target Detection Antenna": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        }
    }
}
```

Listing F.27: The electric power plant system report for the Volunteer Tan scenario (20230706_182029_Electric Power Plant.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Electric Power Plant and its subordinate elements during Volunteer_Tan.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1820 July 2023",
    "Electric Power Plant": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "Generate Electrical Power": {
                "Maximum Capability": "Electrical power is generated by both generator sets",
                "Capability States": {
                    "Via Generator Set 1 and Generator Set 2": true,
                    "NOT POSSIBLE": false,
                    "Via Generator Set 1 or Generator Set 2": false
                }
            },
            "Power Prime Loads": {
                "Maximum Capability": "Powers Command and Control and Target Sensor systems",
                "Capability States": {
                    "Powers C2 and Target Sensor": true,
                    "NOT POSSIBLE": false,
                    "Powers C2 ONLY": false,
                    "Powers Target Sensor ONLY": false
                }
            },
            "Communicate with C2": {
                "Maximum Capability": "Communication with C2 possible via remote control and local control panel",
                "Capability States": {
                    "Via Remote Control and Local Panel": true,
                    "NOT POSSIBLE": false,
                    "Via Local Panel ONLY": false
                }
            }
        },
        "Electric Power Plant": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Set 3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Set 3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Power Distribution Unit": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Air Intake 3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fuel System 3.1": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Engine 3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator 3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Air Intake 3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fuel System 3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Engine 3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator 3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "PDU Controller": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "PDU Synchronizer": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Cable J1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Cable J2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Cable J3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Cable J4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Cable J5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.28: The weapon system 1 report for the Volunteer Tan scenario (20230706_182029_Weapon System 5.1.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.1 and its subordinate elements during Volunteer_Tan.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1820 July 2023",
    "Weapon System 5.1": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Electronics System 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
```

```
                "dynamic pressure"
            ]
        },
        "Fire Control 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Generator Air Intake 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "AC Cabinet 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Data Link Terminal 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Digital Processor 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fiber Optic Modem 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "thermal fluence"
            ]
```

```
        },
        "VHF Radio 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "EMP Suppressor 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Radio Antenna 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed"
            ]
        },
        "Compass 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "GPS Receiver 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "GPS Antenna 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed"
            ]
        },
        "Power Controls 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Motor Controls 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
```

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            ]
        },
        "Traverse & Elevation Mechanisms 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Azimuth Motor 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Elevation Motor 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Heater Control 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Processor Card Cage 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Executive Processor Card 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Interface Card 5.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Junction Box 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.1.1": {
            "Functionality Type": "functional",
```

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            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.1.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.1.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.1.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.1.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.1.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.1.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.1.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
```

```
            ]
        },
        "Ordnance Relay Card 5.1.8": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.1.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.1.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.1.11": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.1.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Canister 5.1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Canister 5.1.5": {
```

```
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Canister 5.1.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Canister 5.1.8": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Canister 5.1.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Canister 5.1.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.1.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.1.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
```

```
        },
        "Ordnance 5.1.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.1.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.1.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.1.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.1.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.1.8": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.1.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.1.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
```

```
        "Ordnance 5.1.11": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.1.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        }
    }
}
```

Listing F.29: The weapon system 2 report for the Volunteer Tan scenario (20230706_182029_Weapon System 5.2.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.2 and its subordinate elements during Volunteer_Tan.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1820 July 2023",
    "Weapon System 5.2": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electronics System 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fire Control 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
```

```
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Generator Air Intake 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fiber Optic Modem 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "VHF Radio 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "EMP Suppressor 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Radio Antenna 5.2": {
```

```
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Compass 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Receiver 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "GPS Antenna 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure",
                "windspeed"
            ]
        },
        "Power Controls 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Motor Controls 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Traverse & Elevation Mechanisms 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Processor Card Cage 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Ordnance Executive Processor Card 5.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Interface Card 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Junction Box 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.2.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.2.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.2.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.6": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.2.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Canister 5.2.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.5": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.2.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.2.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.2.6": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.30: The weapon system 3 report for the Volunteer Tan scenario (20230706_182029_Weapon System 5.3.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.3 and its subordinate elements during Volunteer_Tan.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1820 July 2023",
    "Weapon System 5.3": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Electronics System 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fire Control 5.3": {
```

```
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Generator Air Intake 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "AC Cabinet 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Digital Processor 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Fiber Optic Modem 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "VHF Radio 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "EMP Suppressor 5.3": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Radio Antenna 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Compass 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "GPS Receiver 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "GPS Antenna 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Power Controls 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Motor Controls 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Traverse & Elevation Mechanisms 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Elevation Motor 5.3": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Heater Control 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Processor Card Cage 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Executive Processor Card 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Interface Card 5.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Junction Box 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.3.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.2": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.8": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
```

```
        "Ordnance Relay Card 5.3.11": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance Relay Card 5.3.12": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Canister 5.3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Canister 5.3.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.2": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
        "Ordnance 5.3.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.7": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.8": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.3.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.10": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.31: The weapon system 4 report for the Volunteer Tan scenario (20230706_182029_Weapon System 5.4.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.4 and its subordinate elements during Volunteer_Tan.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1820 July 2023",
    "Weapon System 5.4": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electronics System 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "dynamic pressure"
            ]
        },
```

```
        "Fire Control 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Generator Air Intake 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Radio 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EMP Suppressor 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Radio Antenna 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure",
                "windspeed"
            ]
        },
        "Compass 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "GPS Receiver 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Antenna 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Power Controls 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Motor Controls 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Traverse & Elevation Mechanisms 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Processor Card Cage 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Executive Processor Card 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Interface Card 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Junction Box 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.4.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Data Cable 5.4.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.4.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance Relay Card 5.4.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.10": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance Relay Card 5.4.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Ordnance Relay Card 5.4.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.1": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
```

```
        },
        "Ordnance 5.4.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.3": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.4.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.4.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.4.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.9": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.4.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.11": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Ordnance 5.4.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.32: The weapon system 5 report for the Volunteer Tan scenario (20230706_182029_Weapon System 5.5.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.5 and its subordinate elements during Volunteer_Tan.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1820 July 2023",
    "Weapon System 5.5": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electronics System 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fire Control 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Generator Air Intake 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Radio 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EMP Suppressor 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Radio Antenna 5.5": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Compass 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Receiver 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Antenna 5.5": {
            "Functionality Type": "dysfunctional",
```

```
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Power Controls 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Motor Controls 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Traverse & Elevation Mechanisms 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Processor Card Cage 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Executive Processor Card 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Interface Card 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Junction Box 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.1": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.3": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Ordnance 5.5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.33: The weapon system 6 report for the Volunteer Tan scenario (20230706_182029_Weapon System 5.6.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.6 and its subordinate elements during Volunteer_Tan.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1820 July 2023",
    "Weapon System 5.6": {
        "System Functionality Type": "dysfunctional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power NOT available",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Aims Self": {
                "Maximum Capability": "Does NOT aim self",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can NOT fire primary weapon system",
                "Capability States": {
                    "Possible": false,
                    "NOT POSSIBLE": true
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can NOT communicate with C2 system",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": true,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "15kW Generator Set 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electronics System 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Fire Control 5.6": {
```

```
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "static overpressure"
            ]
        },
        "Generator Air Intake 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Radio 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EMP Suppressor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Radio Antenna 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Compass 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Receiver 5.6": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "GPS Antenna 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Power Controls 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Motor Controls 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Traverse & Elevation Mechanisms 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Processor Card Cage 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Executive Processor Card 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Interface Card 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Junction Box 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.6.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.6.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.6.3": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.2": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Ordnance 5.6.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

F.4.2.2 SOS Graph

Figure F.8 shows the altered SOS graph following NuSCAP analysis during the Volunteer Tan scenario. Black nodes with white text denote dysfunctional nodes. Edges removed from the computational graph are shown in pale gray to provide context.

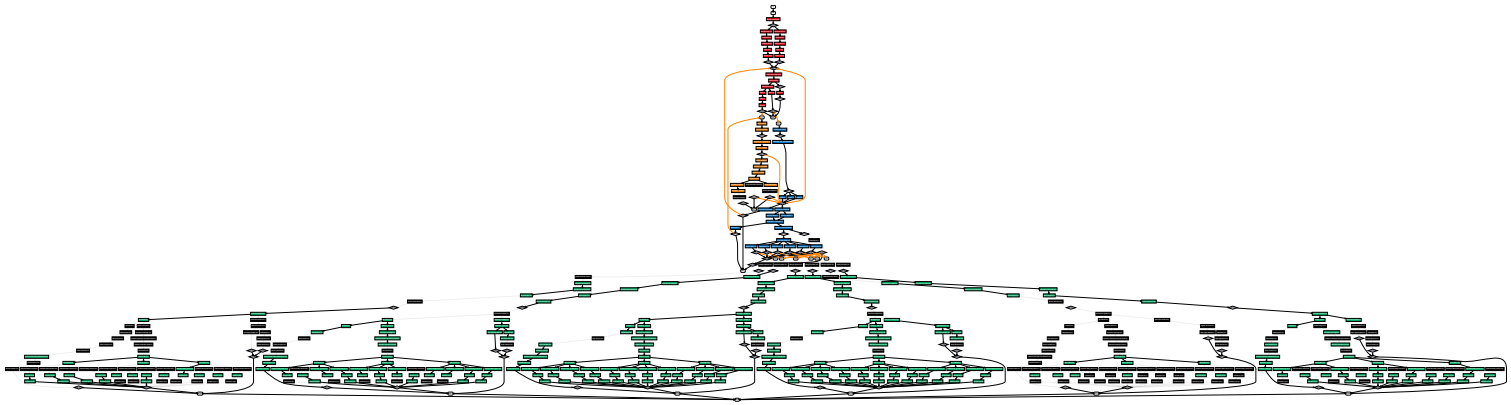


Figure F.8: Post-analysis SOS graph for the Volunteer Tan scenario.

F.4.3 Volunteer Sunrise

F.4.3.1 NuSCAP Reports

Listing F.34: The Reference system-of-system report for the Volunteer Sunrise scenario (20230706_194748_Reference.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality and residual capabilities of Reference during Volunteer_Sunrise. Causes of dysfunction for constitutent systems are also reported.",
    "DTG of Report": "06 1947 July 2023",
    "Reference": {
        "SOS Functionality Type": "functional",
        "Residual Capabilities": {
            "Power Prime Systems": {
                "Maximum Capability": "Powers Command & Control and Target Sensor systems",
                "Capability States": {
                    "Powers C2 & Target Sensor": true,
                    "NOT POSSIBLE": false,
                    "Powers Target Sensor system ONLY": false,
                    "Powers Command & Control system ONLY": false
                }
            },
            "Control Electric Power Plant": {
                "Maximum Capability": "Electric Power Plant control available by remote and local control panel",
                "Capability States": {
                    "Remote and Local Control Possible": true,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": false,
                    "Local Control": false
                }
            },
            "Acquire Targets": {
                "Maximum Capability": "System senses targets and identifes as friend/foe",
                "Capability States": {
                    "Senses and Identifies Targets": true,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "NOT POSSIBLE 4": false,
                    "NOT POSSIBLE 5": false,
                    "Senses Targets ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.1": {
                "Maximum Capability": "Capable of firing ordnance via Fiber Optic or Radio command",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": true,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
```

```
            "Fire Ordnance from Weapon System 5.2": {
                "Maximum Capability": "Capable of firing ordnance via Fiber Optic or Radio command",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": true,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.3": {
                "Maximum Capability": "Capable of firing ordnance via Fiber Optic or Radio command",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": true,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.4": {
                "Maximum Capability": "Capable of firing ordnance via Fiber Optic command ONLY",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": true,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.5": {
                "Maximum Capability": "Capable of firing ordnance via Fiber Optic or Radio command",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": true,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": false,
                    "Fire via Radio ONLY": false
                }
            },
            "Fire Ordnance from Weapon System 5.6": {
                "Maximum Capability": "Capable of firing ordnance via Fiber Optic command ONLY",
                "Capability States": {
                    "Fire via Fiber Optic Cable and VHF Radio": false,
                    "NOT POSSIBLE 1": false,
                    "NOT POSSIBLE 2": false,
                    "NOT POSSIBLE 3": false,
                    "Fire via Fiber Optic Cable ONLY": true,
                    "Fire via Radio ONLY": false
                }
            }
        },
        "Command & Control": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Target Sensor": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Power Plant": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Weapon System 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Weapon System 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Weapon System 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Weapon System 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Weapon System 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Weapon System 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.35: The command and control system report for the Volunteer Sunrise scenario (20230706_194748_Command & Control.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Command & Control and its subordinate elements during Volunteer_Sunrise.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1947 July 2023",
    "Command & Control": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "Protect Personnel and Eqipment": {
                "Maximum Capability": "Protects Personnel and Eqipment",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Control Mobile Power Plant Remotely": {
                "Maximum Capability": "Remote control of Mobile Power Plant possible",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Control Target Sensor Remotely": {
                "Maximum Capability": "Remote control of Target Sensor possible",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Control Weapon System 1": {
                "Maximum Capability": "Can control Weapon System 1 by cable or radio",
                "Capability States": {
                    "Via FO Cable or VHF Radio": true,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 2": {
                "Maximum Capability": "Can control Weapon System 1 by cable or radio",
                "Capability States": {
                    "Via FO Cable or VHF Radio": true,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 3": {
                "Maximum Capability": "Can control Weapon System 1 by cable or radio",
                "Capability States": {
                    "Via FO Cable or VHF Radio": true,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
```

```
            },
            "Control Weapon System 4": {
                "Maximum Capability": "Can control Weapon System 1 by cable or radio",
                "Capability States": {
                    "Via FO Cable or VHF Radio": true,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 5": {
                "Maximum Capability": "Can control Weapon System 1 by cable or radio",
                "Capability States": {
                    "Via FO Cable or VHF Radio": true,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            },
            "Control Weapon System 6": {
                "Maximum Capability": "Can control Weapon System 1 by cable or radio",
                "Capability States": {
                    "Via FO Cable or VHF Radio": true,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Command & Control": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Personnel & Equipment Shelter": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Operations Subsystem": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Soldier 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Soldier 2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Soldier 3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Power Plant Controller": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Operator Station 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Operator Station 2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Target Sensor Computer 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Weapon Control Computer": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Antenna 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Optical Fiber 1.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.36: The target sensor system report for the Volunteer Sunrise scenario (20230706_194748_Target Sensor.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Target Sensor and its subordinate elements during Volunteer_Sunrise.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1947 July 2023",
    "Target Sensor": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "Protect Equipment": {
                "Maximum Capability": "Provides equipment ballistic and environmental protection",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Communicate with C2": {
                "Maximum Capability": "Receives and transmits data with C2",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Detect Targets": {
                "Maximum Capability": null,
                "Capability States": {
                    "Detects and classifies targets": false,
                    "NOT POSSIBLE": false,
                    "Detects targets ONLY": false
                }
            },
            "Guide Ordnance": {
                "Maximum Capability": "Calculates and transmits guidance data to ordnance",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            }
        },
        "Target Sensor": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Equipment Shelter": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Target Sensor Computer 2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Signal Generator": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Transmitter Interface": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Signal Transmitter": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Signal Receiver": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Target Interrogator": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Interrogator Antenna": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Guidance Correlator": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Guidance Processor": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Guidance Antenna": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Target Detection Antenna": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.37: The electric power plant system report for the Volunteer Sunrise scenario (20230706_194748_Electric Power Plant.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Electric Power Plant and its subordinate elements during Volunteer_Sunrise.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1947 July 2023",
    "Electric Power Plant": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "Generate Electrical Power": {
                "Maximum Capability": "Electrical power is generated by both generator sets",
                "Capability States": {
                    "Via Generator Set 1 and Generator Set 2": true,
                    "NOT POSSIBLE": false,
                    "Via Generator Set 1 or Generator Set 2": false
                }
            },
            "Power Prime Loads": {
                "Maximum Capability": "Powers Command and Control and Target Sensor systems",
                "Capability States": {
                    "Powers C2 and Target Sensor": true,
                    "NOT POSSIBLE": false,
                    "Powers C2 ONLY": false,
                    "Powers Target Sensor ONLY": false
                }
            },
            "Communicate with C2": {
                "Maximum Capability": "Communication with C2 possible via remote control and local control panel",
                "Capability States": {
                    "Via Remote Control and Local Panel": true,
                    "NOT POSSIBLE": false,
                    "Via Local Panel ONLY": false
                }
            }
        },
        "Electric Power Plant": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Set 3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Set 3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Power Distribution Unit": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Air Intake 3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Fuel System 3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Engine 3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator 3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Air Intake 3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fuel System 3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Engine 3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator 3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "PDU Controller": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "PDU Synchronizer": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Cable J1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Cable J2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Cable J3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Cable J4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Cable J5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
```

```
110 }
```

Listing F.38: The weapon system 1 report for the Volunteer Sunrise scenario (20230706_194748_Weapon System 5.1.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.1 and its subordinate elements during Volunteer_Sunrise.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1947 July 2023",
    "Weapon System 5.1": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power available",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Aims Self": {
                "Maximum Capability": "Aims self",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can fire one or more rounds of ordnance",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Communicates with C2 via cable or radio",
                "Capability States": {
                    "Via FO Cable or VHF Radio": true,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "15kW Generator Set 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electronics System 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fire Control 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Generator Air Intake 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Radio 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EMP Suppressor 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Radio Antenna 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Compass 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Receiver 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Antenna 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Power Controls 5.1": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Motor Controls 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Traverse & Elevation Mechanisms 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Processor Card Cage 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Executive Processor Card 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Interface Card 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Junction Box 5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.1.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.2": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.1.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Canister 5.1.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.1.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Ordnance 5.1.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.1.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.39: The weapon system 2 report for the Volunteer Sunrise scenario (20230706_194748_Weapon System 5.2.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.2 and its subordinate elements during Volunteer_Sunrise.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1947 July 2023",
    "Weapon System 5.2": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power available",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Aims Self": {
                "Maximum Capability": "Aims self",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can fire one or more rounds of ordnance",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Communicates with C2 via cable or radio",
                "Capability States": {
                    "Via FO Cable or VHF Radio": true,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "15kW Generator Set 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electronics System 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fire Control 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Generator Air Intake 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Radio 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EMP Suppressor 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Radio Antenna 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Compass 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Receiver 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Antenna 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Power Controls 5.2": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Motor Controls 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Traverse & Elevation Mechanisms 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Processor Card Cage 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Executive Processor Card 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Interface Card 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Junction Box 5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.2.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.2.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.2.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.2": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.2.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Canister 5.2.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.2.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Ordnance 5.2.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.2.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.40: The weapon system 3 report for the Volunteer Sunrise scenario (20230706_194748_Weapon System 5.3.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.3 and its subordinate elements during Volunteer_Sunrise.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1947 July 2023",
    "Weapon System 5.3": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power available",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Aims Self": {
                "Maximum Capability": "Aims self",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can fire one or more rounds of ordnance",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Communicates with C2 via cable or radio",
                "Capability States": {
                    "Via FO Cable or VHF Radio": true,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "15kW Generator Set 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electronics System 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fire Control 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Generator Air Intake 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Radio 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EMP Suppressor 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Radio Antenna 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Compass 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Receiver 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Antenna 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Power Controls 5.3": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Motor Controls 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Traverse & Elevation Mechanisms 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Processor Card Cage 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Executive Processor Card 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Interface Card 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Junction Box 5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.3.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.2": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.3.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Canister 5.3.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.3.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Ordnance 5.3.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.3.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.41: The weapon system 4 report for the Volunteer Sunrise scenario (20230706_194748_Weapon System 5.4.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.4 and its subordinate elements during Volunteer_Sunrise.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1947 July 2023",
    "Weapon System 5.4": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power available",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Aims Self": {
                "Maximum Capability": "Aims self",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can fire one or more rounds of ordnance",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can communicate with C2 by cable ONLY",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": true,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "15kW Generator Set 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electronics System 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fire Control 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Generator Air Intake 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Radio 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EMP Suppressor 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Radio Antenna 5.4": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Compass 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Receiver 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Antenna 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Power Controls 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Motor Controls 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Traverse & Elevation Mechanisms 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Processor Card Cage 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Executive Processor Card 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Interface Card 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Junction Box 5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.4.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.4.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.4.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Ordnance Relay Card 5.4.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.4.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.4": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.4.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.6": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.4.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.42: The weapon system 5 report for the Volunteer Sunrise scenario (20230706_194748_Weapon System 5.5.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.5 and its subordinate elements during Volunteer_Sunrise.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1947 July 2023",
    "Weapon System 5.5": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power available",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Aims Self": {
                "Maximum Capability": "Aims self",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can fire one or more rounds of ordnance",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Communicates with C2 via cable or radio",
                "Capability States": {
                    "Via FO Cable or VHF Radio": true,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": false,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "15kW Generator Set 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electronics System 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fire Control 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Generator Air Intake 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Radio 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EMP Suppressor 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Radio Antenna 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Compass 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Receiver 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Antenna 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Power Controls 5.5": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Motor Controls 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Traverse & Elevation Mechanisms 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Processor Card Cage 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Executive Processor Card 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Interface Card 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Junction Box 5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.2": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.5.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Canister 5.5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.5.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Ordnance 5.5.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.5.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

Listing F.43: The weapon system 6 report for the Volunteer Sunrise scenario (20230706_194748_Weapon System 5.6.out.json)


```
{
    "HEADER COMMENTS": "This file reports the functionality of Weapon System 5.6 and its subordinate elements during Volunteer_Sunrise.  Causes of dysfunction and residual capabilities are also included.",
    "DTG of Report": "06 1947 July 2023",
    "Weapon System 5.6": {
        "System Functionality Type": "functional",
        "Residual Capabilities": {
            "Power Self": {
                "Maximum Capability": "Power available",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Aims Self": {
                "Maximum Capability": "Aims self",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Fires Primary Weapon Ordnance": {
                "Maximum Capability": "Can fire one or more rounds of ordnance",
                "Capability States": {
                    "Possible": true,
                    "NOT POSSIBLE": false
                }
            },
            "Communicate with Command and Control System": {
                "Maximum Capability": "Can communicate with C2 by cable ONLY",
                "Capability States": {
                    "Via FO Cable or VHF Radio": false,
                    "NOT POSSIBLE": false,
                    "Via FO Cable ONLY": true,
                    "Via VHF Radio ONLY": false
                }
            }
        },
        "Weapon System 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "15kW Generator Set 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electronics System 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fire Control 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Generator Air Intake 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Generator Fuel System 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Diesel Engine 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Electric Generator 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "AC Cabinet 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Link Terminal 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Digital Processor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Fiber Optic Modem 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "VHF Radio 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "EMP Suppressor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Radio Antenna 5.6": {
            "Functionality Type": "dysfunctional",
            "Cause(s) of Dysfunction": [
                "windspeed"
            ]
        },
        "Compass 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Receiver 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "GPS Antenna 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
```

```
        },
        "Power Controls 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Motor Controls 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Traverse & Elevation Mechanisms 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Azimuth Motor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Elevation Motor 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Heater Control 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Processor Card Cage 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Executive Processor Card 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Interface Card 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Junction Box 5.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.6.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.6.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Data Cable 5.6.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
```

```
        "Ordnance Relay Card 5.6.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance Relay Card 5.6.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.4": {
```

```
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.6": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Canister 5.6.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.1": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.2": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.3": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.4": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.5": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.6": {
            "Functionality Type": "functional",
```

```
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.7": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.8": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.9": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.10": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.11": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        },
        "Ordnance 5.6.12": {
            "Functionality Type": "functional",
            "Cause(s) of Dysfunction": []
        }
    }
}
```

F.4.3.2 SOS Graph

Figure F.9 shows the altered SOS graph following NuSCAP analysis during the Volunteer Sunrise scenario. Black nodes with white text denote dysfunctional nodes. Edges removed from the computational graph are shown in pale gray to provide context.

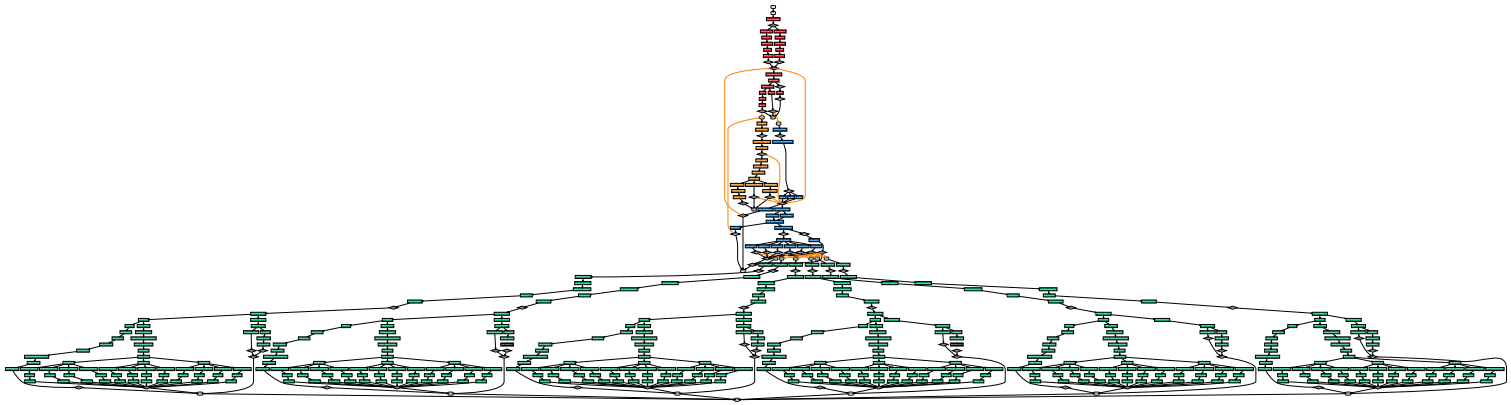


Figure F.9: Post-analysis SOS graph for the Volunteer Sunrise scenario.

Appendix G

Operationally Relevant Application

Commentary on specific operationally relevant impacts of this study are contained in a limited distribution document "(U) Current Operational Relevance of the NuSCAP Method" by R. B. Gilbreath[174].

Vita

Anything in life worth doing is worth overdoing. Moderation is for cowards.

Alexander Ludwig

as Petty Officer Second Class (SEAL) Shane E. Patton,

in *Lone Survivor*

Robert Boone Gilbreath was born to Lonnie and Donna Gilbreath in Fort Smith, Arkansas in 1986. Boone was raised in nearby Greenwood, Arkansas where he graduated with honors from Greenwood High School in 2004. He went on to graduate Cum Laude from Arkansas Tech University in 2008 with the AS degree in Nuclear Technology and the BS degree in Mechanical Engineering. Upon graduation, Boone was commissioned a second lieutenant in the US Army Ordnance Corps through Arkansas Tech's ROTC program. He completed initial entry training at Fort Benning, Georgia and Aberdeen Proving Ground, Maryland where he graduated with honors from the Ordnance Basic Officer Leader Course. Boone's time as a company grade officer included duties as Maintenance Platoon Leader, Maintenance Control Officer, Forward Support Troop Executive Officer, and Company Commander in 1st Armored Brigade Combat Team, 4th Infantry Division. He deployed to Camp Stone, Herat Province, Afghanistan in support of Operation Enduring Freedom from 2010–2011 with Forward Support Troop D, 7th Squadron, 10th US Cavalry Regiment. The squadron received the Valorous Unit Award in recognition of its extraordinary heroism in action against an armed enemy throughout northwestern Afghanistan during that time. Following company command, Boone graduated with honors from the Combined Logistics Captains Career Course (CLC3) at Fort Lee, Virginia where he subsequently served as Assistant Director of Training at the US Army Transportation School. From 2015–2017, he attended the University of Tennessee where he earned the MS degree in Nuclear Engineering. During his subsequent utilization tour, Boone served as Instructor and, later, Assistant Professor in the US Military Academy's Department of Physics and Nuclear Engineering (PANE). From 2020–2023, Boone was assigned as a Guest Scientist at Los Alamos National Laboratory and a graduate student in the Department of Nuclear Engineering at the University of Tennessee where he recently completed the requirements for the

PhD degree. While pursuing his doctorate, MAJ Gilbreath concurrently earned recognition as a Superior Graduate of the United States Army Command and General Staff Officer Course. Boone also holds graduate certificates in Nuclear Security Science and Analysis from the University of Tennessee and Nuclear Weapon Effects, Policy, and Proliferation from the Air Force Institute of Technology. His research interests include nuclear weapons effects, radiation transport, systems analysis, and post-detonation nuclear forensics. Boone has been married to his high school sweetheart, Jessica (née Carter), since 2007; together they have two sons, Thomas and Samuel. As of September 2023, Major Gilbreath serves as a Strategic Analyst with the US Strategic Command at Offutt Air Force Base, Nebraska.