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4

SYSTEMS INTERACTION ANALYSIS OF THE CLINCH RIVER BREEDER REACTOR PLANT SHUTDOWN HEAT REMOVAL SYSTEM

A Thesis

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ABSTRACT

Systems interaction analyses are an important extension to the Probabilistic Risk Assessment (PRA) method used in The Reactor Safety Study (WASH-1400) and in more recent PRAs. Systems interaction analyses allow the analyst to study the coupling of engineered safety features through shared support systems, common maintenance activities, and plant operational procedures. This type of analysis makes use of a modified fault tree, or systems interaction fault tree, which includes potential systems interaction candidates. A systems interaction candidate is a system which, if failed, would cause the components it supports to malfunction. Consequently, a systems interaction analysis will provide the analyst with previously unrecognized failure modes caused by support system failures.

This systems interaction analysis of the Clinch River Breeder Reactor Plant Shutdown Heat Removal System (CRBRP SHRS) demonstrates the application of systems interaction analysis methodology. The results of this analysis show that the CRBRP SHRS is not as redundant as previous studies have indicated. For example, previous studies have determined no one-event minimal cut set (single-failure point) and only one two-event minimal cut set (one double-failure point). This analysis identifies several previously unrecognized failure modes, including two additional double-failure points. As expected, no additional single-failure points were found. This study also shows a greater dependence between the Primary Heat Transport System (PHTS) and the Direct Heat Removal System (DHRS) than previous studies of the SHRS have indicated.

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GLOSSARY

Availability - the probability that a malfunction of interest does not exist at some specific time t.

Basic Event - a component malfunction.

Component - the smallest system entity considered in an analysis.

Expected Number of Failures - the expected number of times a specified malfunction will occur during a given time interval.

Failure Rate - the failure rate, , is defined such that dt is the probability a malfunction will occur in the time interval t to t+dt given that the malfunction has not occurred to time t.

Fault Tree - a diagram composed of Boolean logic symbols that shows the logical development of the TOP event.

Front Line System - a system whose primary function is to mitigate the consequences or prevent the occurrence of the TOP event.

Functional Fault Tree - a fault tree that models interfaces between front line systems only.

Interfacing System - a plant system or subsystem that provides support to plant components.

Mean Repair Time - the mean time from the instant the component fails to the instant the component is restored to service.

Minimal Cut Set - a collection of basic events such that the simultaneous existance of all the events is sufficient to cause the TOP event to occur and no proper subset will guarantee the occurrence of the TOP event.

Minimal Path Set - a smallest collection of basic events, such that if all the basic events simultaneously do not exist then the TOP event is guaranteed to be in the unfailed state.

Nonexistance Probability - the probability that a malfunction does not exist at a specific time t.

Phased Mission - a task to be performed by a system, during the execution of which the system configuration is altered such that the failure logic model changes at one or more times.

Rate of Failure - the expected number of times a specified malfunction occurs at time t, per unit time.

Reliability - the probability that a malfunction of interest has not occurred during a specified time interval.

Support System - a system that provides support to a front line system and whose failure may increase the probability of failure of that front line system.

Systems Interaction - exists if two conditions are satisfied: (1) there must be the potential for a failure of a specified function of a system, (2) at least one malfunction of an interfacing system must contribute to the failure of interest.

Systems Interaction Candidate - a system which, if failed, would cause the component(s) it supports to malfunction.

System Interface Tables - tables that identify front line and support systems whose failure may increase the probability of failure of a TOP event.

TOP Event - the system failure of interest.

Unavailability Importance of a Cut Set - the time dependent probability that the cut set is failed given the TOP event is failed.

Unavailability Importance of a Basic Event - the time dependent probability that the basic event is a contributor to the existence of the TOP event given the TOP event is failed.

Unreliability Importance of a Cut Set - the time dependent probability that the cut set caused the first occurrence of the TOP event, given the TOP event has occurred.

Unreliability Importance of a Basic Event - the time dependent probability that the basic event contributed to the first occurrence of the TOP event, given that the TOP event has failed.

CHAPTER 1

INTRODUCTION

1.1 Background

The unresolved issue of how equipment failures in nonsafety-related systems may affect safety-related equipment is currently a major concern in the nuclear industry[1]. Although there are many accepted risk assessment methods for identifying the reliability and safety of a particular system, there has been little effort to develop methods for determining how equipment failures in one system may affect the operation of other systems. Thus, there is no standard methodology to identify and evaluate interactions between systems, or simply, "systems interactions."

This thesis presents a method for analyzing systems interactions, and it applies this method to the Clinch River Breeder Reactor Plant Shutdown Heat Removal System (CRBRP SHRS). The methodology here expands the techniques presented by Battelle Columbus Laboratories[2], Brookhaven National Laboratory[3], and Lawrence Livermore Laboratory[4]. These laboratories recommend that several analysis techniques be used simultaneously to analyze systems interactions.

EBASCO Services, Inc. was one of the first to publish a systems interaction analysis. They analyzed the interactions between support systems and the feedwater system at the Indian Point 3 Nuclear Power Plant using fault trees, failure modes and effects methods, and actual plant data gathered by direct system inspection[5].

Modeling system failures with fault trees provides significant information about interfaces between systems. This thesis concentrated

on fault tree analysis techniques since fault trees may be developed using only design information.

1.2 Objectives

The main objective of this study is to present a methodology for analyzing potential systems interactions using fault tree models and design information. A case study on the CRBRP SHRS illustrates the application of this methodology. The step-by-step approach used here is consistent with, but improves upon, the state-of-the-art methods reported by three national laboratories[2-4]. The second objective of this study is to use this methodology to analyze the interactions of several CRBRP safety-related systems that are affected by a specific event. That is, the methodology applied here is used to determine potential systems interactions for the CRBRP systems affected by the event "loss of forced convection cooling to the CRBRP reactor core during reactor shutdown given loss of offsite electrical power."

1.3 Systems Interaction Definition

A systems interaction exists if two conditions are satisfied: first, there must be the potential for a failure of a specified function of a system. This "failure of interest" can be defined as required by the analyst. For example, a failure of interest could be the total failure of an entire function, or it could be merely a degradation of capability below a satisfactory level. Using a pump as an example, the pump could fail because coolant to the pump is completely lost, or the pump could fail because coolant is still available but the coolant temperature is not low enough to keep the pump from overheating.

The second condition required for a systems interaction to exist is that at least one malfunction of an interfacing system must contribute to the failure of interest. An interfacing system is a plant system or subsystem that provides support to plant components. The failure of the interfacing system will cause the failure of the component it supports. Consider again a pump and the part it plays in a systems interaction. The failure of interest in this example will be the "loss of capability to remove decay heat from the reactor core." The cooling system to the pump's oil unit cooler becomes the interfacing system. Failure of the cooling system will cause the failure of interest if the pump is required to remove decay heat from the reactor core.

The above definition differs from others previously presented[2-4] in two ways. First, as defined here, the failure of interest need not pertain to a safety function; however, safety functions often merit systems interaction analyses. Secondly, degradation of a function is considered a failure if it causes the plant to operate in an unsatisfactory condition.

There are three types of systems interactions: functional, spatial, and human. A functional interaction is the physical interaction between systems and components. This type interaction is described above and is the systems interaction considered in this analysis. A spatial interaction is an interaction between systems caused by a common cause in a common location. For example, a fire in a location containing electrical cabling for two different systems, could render both systems inoperable. Additionally, a failure in one system can affect the operability of another system just because the systems share a common

location. For example, a pipe rupture and subsequent pipe whip in one system could render several other systems near the pipe inoperable. Performing a common cause failure analysis[6] on the systems interaction fault tree would identify the spatial systems interactions. A complete spatial analysis could be performed on the CRBRP SHRS with the use of design data, a plant model, or once the plant is built, with the use of plant walk-thrus. The last type of systems interaction is a human interaction. Operators, maintenance personnel, administrative personnel, and personnel involved in the installation and fabrication of equipment are examples of human interactions. A human factors analysis would be required to identify human interactions.

1.4 Organization

Chapter 2 describes the methodology for developing a systems interaction fault tree and for performing the qualitative and quantitative evaluations of failures associated with complex systems. Chapter 3 describes the systems interaction analysis of the Clinch River Breeder Reactor Plant Shutdown Heat Removal System (CRBRP SHRS). The results of this analysis are discussed in Chapter 4, and Chapter 5 offers recommendations for performing efficient systems interaction analyses in the future.

Appendicies A through D of this report contain the logic models and the system interface tables used in the analysis of the CRBRP SHRS. Appendix E contains the logic model identification codes used for interpreting basic event names. The qualitative results of this analysis are provided in Appendicies F, G, and H. These appendicies list the two- and three-event minimal cut sets for the functional,

primary interface, and secondary interface level fault trees. Appendix I contains the failure data used in the quantitative analysis while Appendix J provides the results of the quantitative analysis (i.e., the unavailability importance of the most important components verses time).

CHAPTER 2

METHODOLOGY

The major objective of this thesis is to present a methodology for analyzing potential systems interactions using fault tree models and design data and to demonstrate the use of this methodology in a systems interaction analysis of the CRBRP SHRS. The methodology consists of six major steps: (1) functional fault tree construction, (2) development of system interface tables, (3) systems interaction fault tree construction, (4) qualitative analysis, (5) quantitative analysis, and (6) recommentations. The results from performing a systems interaction analysis are useful in determining system design changes that lead to improved system reliability. The methodology described here only applies to functional systems interactions. The first five steps are described below.

2.1 Functional Fault Tree Construction

The first step in performing any reliability analysis is to identify the specific "failure of interest", called the TOP event, for which a more detailed analysis is desired. The failure of a safety system that is required during any off-normal operation is a typical failure which might require such a detailed analysis. In the example used in this thesis, the failure of interest is "loss of capability of the CRBRP SHRS to provide forced convection cooling to the reactor core during shutdown given loss of offsite power." This specific failure of interest (our problem definition) includes both analytical and physical

bounds established for performing the qualitative and quantitative analyses. The analytical bounds established for the system malfunction of interest, or the TOP event, include initial system operating conditions, events with zero existence probabilities, and necessary or simplifying assumptions. The initial conditions describe the initial configuration of all components which have more than one operating state. For example, a valve may be open or closed. The state must be identified so that proper component failure modes are used in the development of the fault tree. Analytical bounds also define certain events with zero or unity existence probabilities. Sabotage and acts of war are two examples of events that often are assigned a zero probability of occurrence.

The physical bounds of a system define the space within which components will be considered part of the system being analyzed. If, for example, an analysis defines containment as a physical boundary, then no components outside containment would be considered in the analysis.

Once the analyst has defined analytical and physical bounds for the analysis, he must identify the logical relationship of the basic events (component failures) to the TOP event[8]. This is where front line system behavior is modeled in a fault tree for the TOP event.

The resulting fault tree, which models interfaces between front line systems only, is defined here as a "functional fault tree." This is the fault tree developed in current risk assessments and is the starting point for this systems interaction analysis of the CRBRP SHRS.

As defined here, a functional fault tree is distinguished from other fault trees. Functional fault trees model relationships between front line systems and do not consider relationships between support systems (support system interactions). The analyst uses functional fault trees to identify all of the active components in front line systems that require support. This information is then used to develop system interface tables and systems interaction fault trees to model the relationship between front line systems and support systems for a complete systems interaction analysis.

2.2 System Interface Tables

Once the functional fault tree has been developed, the next step in a systems interaction analysis is to prepare system interface tables. These tables list all front line and support systems whose failure may affect the failure of interest. These tables must include the support system to each active component modeled in the front line systems (the functional fault tree). Appendix B contains the system interface tables for the CRBRP front line and support systems. Each front line and support system included in the tables is then analyzed to determine which systems can provide direct support to any of the other systems listed in the tables. For example, the CRBRP Direct Heat Removal System (system 81 in Appendix B) has sixteen support systems. However, all sixteen support systems do not support every active component. Consider one of the sodium makeup pumps in the Direct Heat Removal System. Only two support systems directly support the sodium makeup pump--the Recirculation Gas Cooling System (system 28) and the Building Electrical Power System (system 12).

Identifying all important front line and support systems and eliminating those that do not directly affect the operability of the active components allows the analyst to proceed to the next step of a systems interaction analysis: the construction of a systems interaction fault tree.

2.3 Systems Interaction Fault Tree Construction

When constructing a systems interaction fault tree, the analyst considers the original analytical bounds established for the functional fault tree. However, it may be necessary to redefine the physical bounds of the analysis when constructing the systems interaction fault tree. Assume, for example, that containment is the physical bound for the functional fault tree. If the Emergency Plant Service Water System (located outside containment) provides direct support to the Emergency Chilled Water System (located inside containment), then the analyst must redefine the physical bounds of the analysis to include those components located outside containment.

After developing the functional fault tree and system interface tables, redefining (if necessary) the physical and analytical bounds of the analysis, the analyst can develop the systems interaction fault tree. First, each active component and its associated front line system must be identified. Next, the analyst concentrates on one particular component and identifies the system interface table where that component belongs. All systems which directly support the component under consideration are identified. For example, the makeup pump in the Direct Heat Removal System receives support directly from the Building Electrical Power System (among others).

In identifying the support systems, all of the initial conditions and bounds of the analysis must be satisfied. If a common cause failure analysis is to be performed as part of the systems interaction analysis, spatial interactions must be considered. The common cause analysis is an extension of a systems interaction analysis, but is not considered in this systems interaction analysis of the CRBRP.

Once all possible support systems to a particular component have been identified, the analyst must determine whether the failure of any of these support systems will cause the failure of the component. If the failure of the support system will cause the component to fail, a fault tree showing the relationship of that support system to that component is drawn. This procedure is repeated for all active components modeled in the functional fault tree.

The analyst now has all of the tools required to transform a functional fault tree into a systems interaction fault tree. The only remaining question is how this is to be done. The analyst must consider all possible failure modes for each component. Since all possible failure modes can never be identified, the analyst classifies the component failure as a "basic failure." The component's basic failure, in essence, becomes a TOP event, and the analyst develops a fault tree for this new TOP event. This new TOP event can occur due to several different failure modes. First, the failure of the support system identified earlier would cause the active component to fail. This is just one possible failure mode for that component. However, this support system failure mode is separated from all of the other possible failure modes. Therefore, to complete the fault tree 'transformation,'

each support system fault tree and the component's basic failure are combined with a logic 'OR' gate. The logic gate is always an OR gate for this transformation since the component can fail due to a basic failure--OR--the component can fail due to the failure of the support system. This combination of support system failures and the corresponding component's failure replaces the basic component failure (basic event) in the functional fault tree (Figure 2.1). When this transformation has been completed for all active components in the functional fault tree, the systems interaction fault tree is complete.

This fault tree is more accurately designated as a systems interaction fault tree at the primary interface level, and it identifies only interactions between support systems and front line systems. A complete systems interaction analysis, however, would also consider support system-to-support system interactions for two reasons. First, a support system that does not directly cause the failure of one front line system could affect other support systems and indirectly contribute to the failure of the same front line system. Figure 2.2 illustrates this point. Assume that the front line system will fail if support system A fails. Assume also that if support system B fails, support system A will fail which in turn will cause the front line system to fail. Therefore, the failure of support system B will indirectly contribute to the failure of the front line system, and a complete systems interaction analysis should model these support system-to-support system interfaces.

Examining interfaces between support systems also allows the analyst to identify other factors--such as design errors--that are not normally

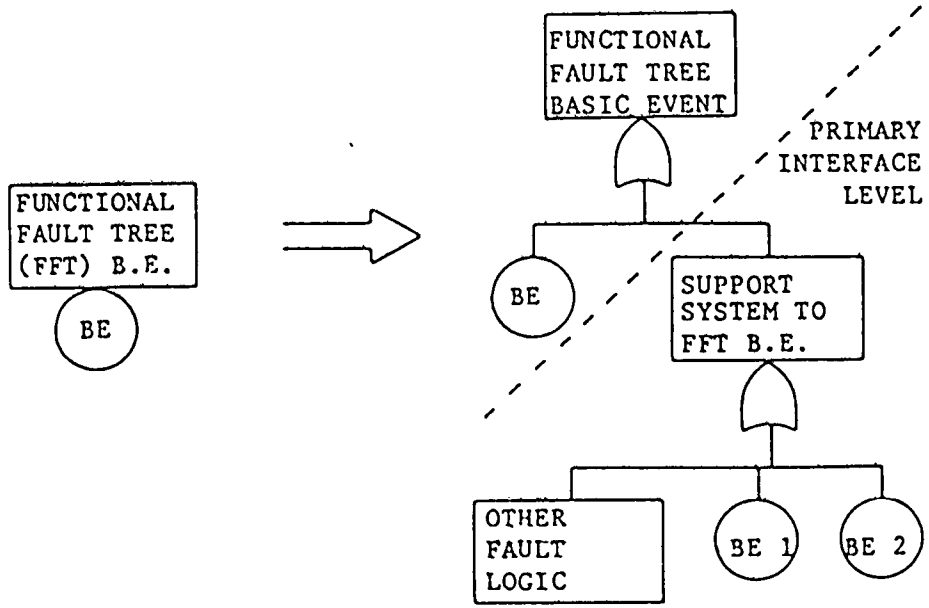


Figure 2.1. Transformation of basic event from functional fault tree to basic event in systems interaction fault tree at the primary interface level.

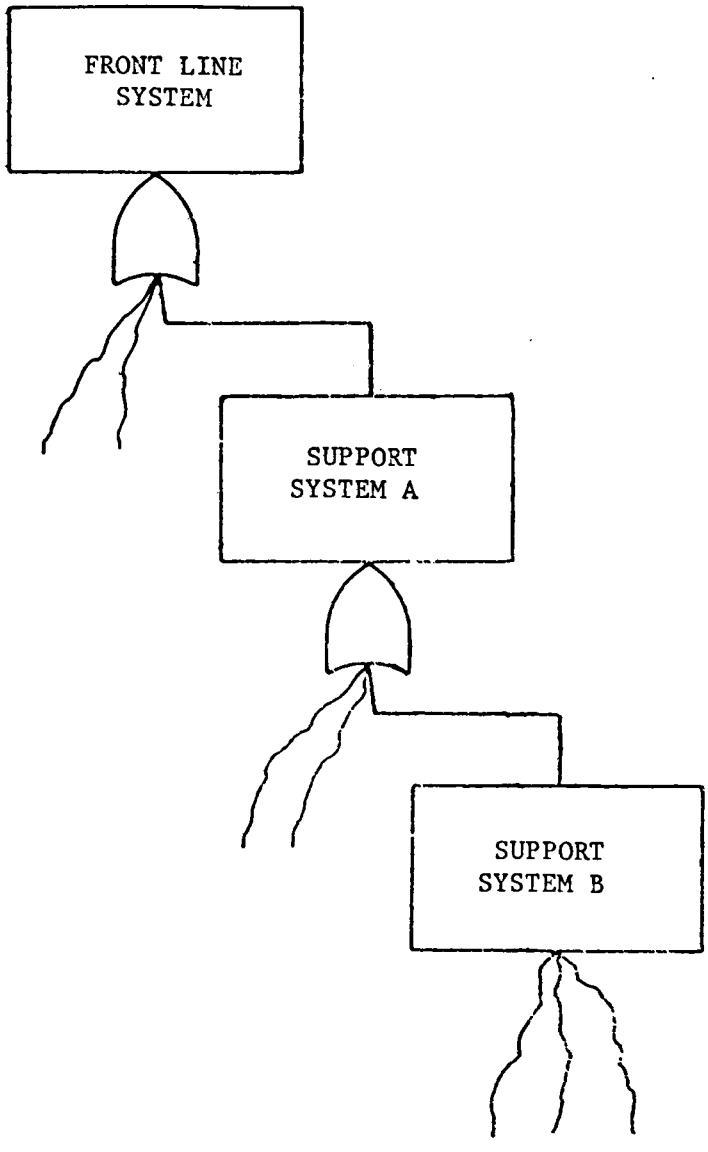


Figure 2.2. Failure of a support system indirectly causing the failure of a front line system.

identified in a systems interaction fault tree at the primary interface level, but which should be considered in a complete systems interaction analysis. As an example, consider the simple illustration in Figure 2.3. According to the assumed system design, the TOP event will occur only if the "AND" logic of Gate I is satisfied. That is, the TOP event, or system failure of interest, will occur only if front line system A and front line system B fail. What happens however, if the failure of support system 1 causes support system 3 to fail? The TOP event will occur if front line systems A and B both fail or, more importantly, if support system 1 fails. Consequently, systems that may apppear to be redundant may not be. This is another reason that all support system interfaces should be considered for a complete analysis of the TOP event. For a specific example, the two separate trains in the CRBRP's Emergency Chilled Water (ECW) System appear to be redundant in every way--separate electrical power supplies, different cell locations, redundant pumps, etc. The Emergency Plant Service Water System supplies water to the two ECW trains from two separate towers. However, both towers receive water from the same cooling tower basin. Consequently, what appears to be redundant systems is not when evaluated at this interface level.

Fault trees which model these front line system-to-support system-to support system interfaces are defined as systems interaction fault trees at the secondary interface level. Standard nomenclature is to define a fault tree according to the support system that is furthest removed from the front line system (in this case the front line system is twice

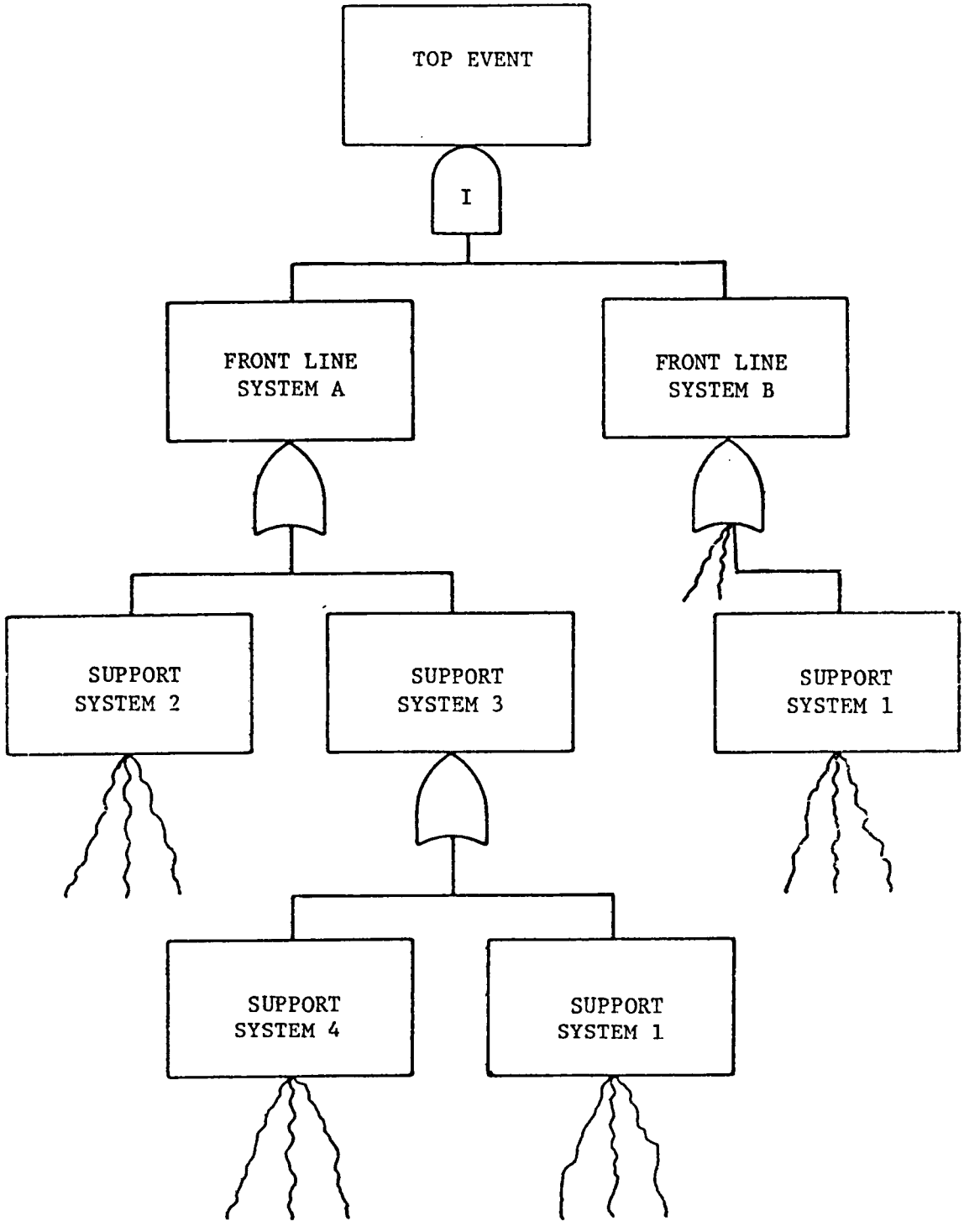


Figure 2.3. Fault tree logic reduction due to systems interactions.

removed--hence the designation secondary interface level). Accordingly, a fault tree with at least one system removed three times (i.e., front line system-to-support system-to-support system-to-support system) is called a systems interaction fault tree at the tertiery interface level.

The development of the systems interaction fault tree at the secondary level (and subsequent levels) proceeds in the same manner as the development of a fault tree at the primary interface level. This time, however, each active component in a support system (as compared to a component in a front line system) behaves as a TOP event. Again, the system interface tables identify possible support systems to that component. These support systems are screened, and each system whose failure will cause the failure of the component is developed. Each support system fault tree and the basic failure mode for the component are combined with a logic "OR" gate as before. This combination of support system failures and basic component failures replaces the basic component failure in the systems interaction fault tree at the primary (previous) interface level. Once this has been completed for all support system components at the primary level, the systems interaction fault tree at the secondary (or subsequent) level is complete. Figure 2.4 shows the transformation from a functional fault tree--to a systems interaction fault tree at the primary interface level--to a systems interaction fault tree at the secondary interface level.

When performing a systems interaction analysis, the analyst should consider three other things. First, all direct system interfaces (front line system-support system, or support system-support system) are

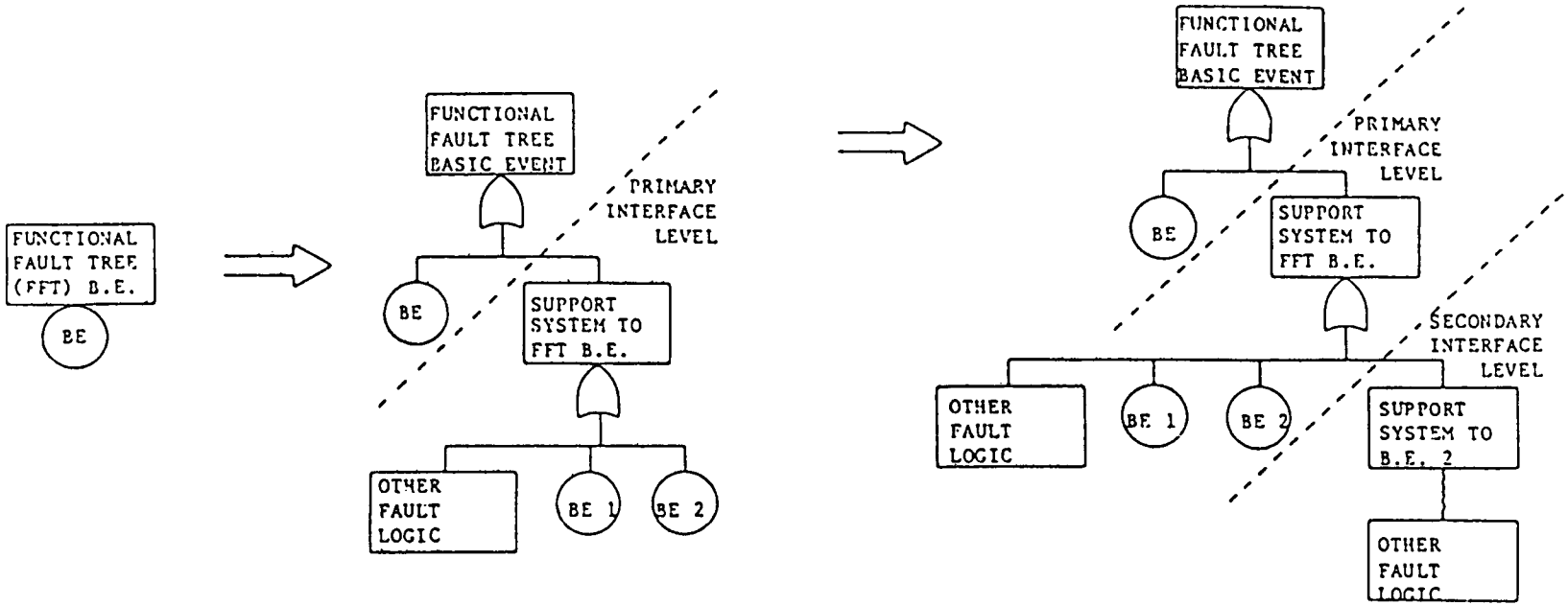


Figure 2.4. Transformation of basic event from functional fault tree to basic event in systems interaction fault tree at the secondary interface level.

primary interfaces with respect to each other. This definition applies even if a fault tree is analyzed at, for example, the tertiery interface level. Also, the quality of the systems interaction analysis heavily depends on the completeness of the "event to interfacing system" transformation. A very large system, such as an electrical power system, may require resolution into smaller subsystems. Finally, some support systems have independent trains and loss of support in one area of the plant may not influence support in another area. For example, the loss of Recirculation Gas Cooling Train MA to sodium makeup pump 1 will not affect the operation of sodium makeup pump 2 since Recirculation Gas Cooling Train MB supports sodium makeup pump 2.

2.4 Qualitative Analysis

Qualitative analyses of fault trees consist of determining the minimal cut sets. A minimal cut set is the smallest collection of basic events that is sufficient to cause the TOP event (failure of interest) if all the basic events in that minimal cut set exist simultaneously. If any of the basic events do not exist, the TOP event cannot occur as a result of that minimal cut set.

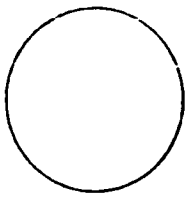
A qualitative analysis performed on a systems interaction fault tree is performed identically as that for a standard fault tree. The PREP computer program[9] was used to compile the minimal cut sets for this research. PREP consists of two parts: TREBIL and MINSET. TREBIL (for "tree build") takes the imput description of a fault tree and builds a FORTRAN subroutine of the Boolean equations for the logic of the fault tree. MINSET then uses the TREE subroutine produced by TREBIL to find

the fault tree's minimal cut sets. MINSET tests all combinations of basic events--one at a time, then two at a time, and so forth--up to a user-specified limit. Those combinations which satisfy the logical equation are cut sets. All cut sets are then sorted to delete supersets, leaving only minimal cut sets.

A fault tree is a graphical representation of Boolean logic associated with the development of a system failure of interest (TOP event). Figure 2.5 presents the fault tree symbols used in this study. As an example of determining minimal cut sets, consider the fault tree in Figure 2.6. This fault tree example can be interpreted as follows: the TOP event will occur if basic event 1 and intermediate event 1 occur simultaneously. Intermediate event 1 occurs if basic event 2 or intermediate event 2 occurs. Intermediate event 2 is caused by simultaneous occurrence of basic events 3 and 4. Hence, two minimal cut sets are produced: one with basic events 1 and 2, the other with basic events 1 and 3 and 4.

2.5 Quantitative Analysis

The results from the qualitative analysis are used as input for the quantitative analysis to determine the time-dependent availability and reliability of the system analyzed. As in the case of the qualitative analysis, a quantitative analysis on a systems interaction fault tree is performed identically as that for a standard fault tree. The availability of a system is the probability that the system is not in a failed state during a specified time. The probability a system has experienced no failures during a specified time interval is the reliability of the system. Using KITT[9] or SPOCUS[10], the analyst can

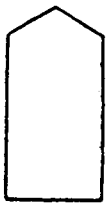


The circle is used to represent basic events in a fault tree.

The rectangle is used to represent intermediate events and the TOP event in a fault tree. The event in a rectangle is the output event of the gate below the rectangle.

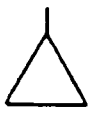
OR gate
The output event associated with this gate is in its failed state if at least one of the input events is in its failed state.

AND gate
The output event associated with this gate occurs only if all of the input events are simultaneous occurring.



HOUSE event
The event contained in this symbol is considered external to the analysis.

in



out

Transfer symbols are used to transfer an entire part of the fault tree to other locations in the tree.

Figure 2.5. Fault tree symbols.

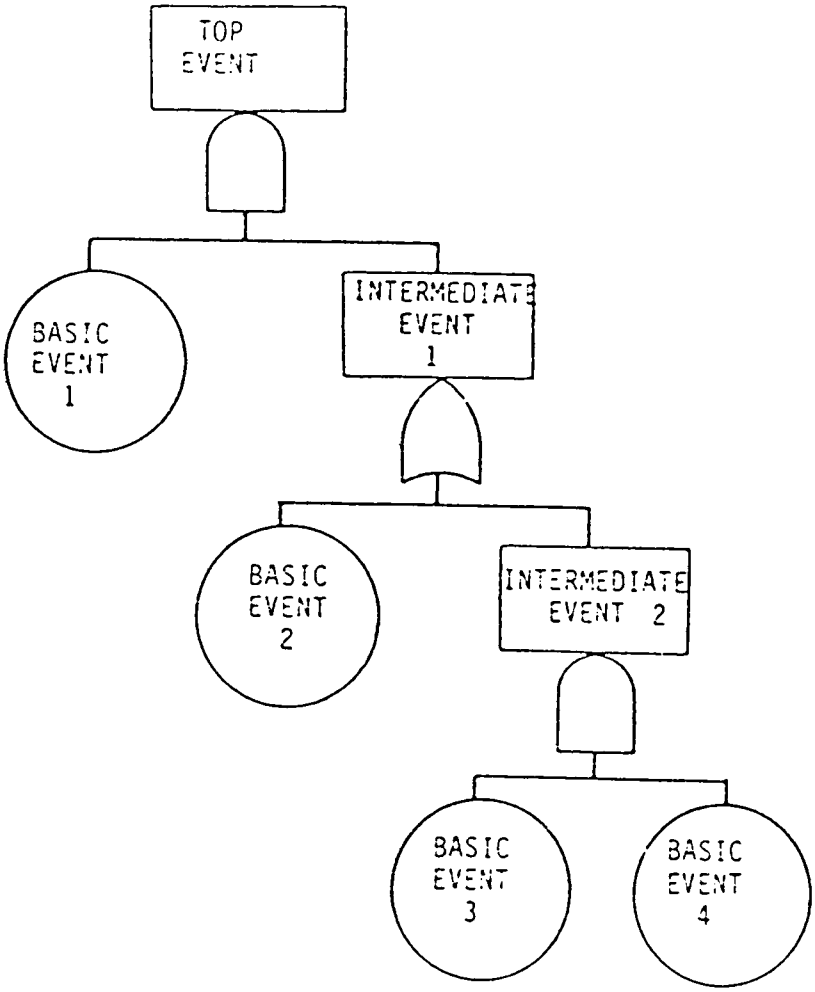


Figure 2.6. Sample fault tree.

calculate the reliability and availability (and therefore the unreliability and unavailability) of a system. The results of quantitative analyses can then be used to make recommendations in areas such as (1) the integration of reliability and safety into system design, (2) the selection among design alternatives, and (3) the specification of design modifications for improved system safety and availability.

The reliability is numerically equal to the availability of a system if the system is totally nonrepairable. In common practice all system components are considered nonrepairable and system unavailability is thereby largely overpredicted in most cases because the probability of a redundant component failing and then being repaired without the system failure occurring is not taken into account. The computer program SPOCUS was used in this analysis of the CRBRP SHRS.

The data required for a quantitative reliability analysis are the failure rates, λ, for each basic event and, if the component is repairable, the mean time to repair, τ, for each basic event. This analysis assumes all basic events are nonrepairable. The failure rate, λ, of each basic event then is defined such that $\lambda(t)dt$ is the probability that the basic event is in the failed state at time $t + dt$, given the basic event has not occurred to time t. The failure rate is assumed to be constant over time. Values of λ for the basic events are tabulated in the literature[11].

Table 2.1 defines symbols commonly used in reliability calculations. Using this standard symbology and the above definitions for failure rate and the mean time to repair, the analyst can calculate

Table 2.1 Notations and definitions of common reliability terms

SYMBOL	TERM	DEFINITION
$\bar{a}_i; \bar{A}_k; \bar{A}_T$	UNAVAILABILITY	Probability the fault event exists at some specified time, t.
$\bar{r}_i; \bar{R}_k; \bar{R}_T$	UNRELIABILITY	Probability the fault event occurs during a specified time interval, usually 0 to t.
$\lambda_i; \Lambda_k; \Lambda_T$	FAILURE RATE	Defined so λ dt is the probability the fault event occurs between t and t+dt given it has not occurred before t.
$\tau_i; \tau_T$	MEAN DEAD TIME	Average time the fault event exists.
I_K	MINIMAL CUT SET IMPORTANCE	Probability the cut set is causing system failure given the system is failed.
i_i	BASIC EVENT IMPORTANCE	Probability the basic event is contributing to system failure given the system is failed.

SUBSCRIPTS

i - Basic Event
k - Minimal Cut Set
T - Top Event

the reliability of a basic event (assumming a constant failure rate) by using this equation:

$$r_i(t) = 1 - \lambda_i t$$

where

$r_i(t)$ = the reliability of the basic event at time t,

λ_i = the failure rate of the basic event, and

t = time.

If the system (or basic event) is nonrepairable, the availability of the basic event equals the reliability of that basic event (i.e., $a_i=r_i$). Also in this case, the unavailability of the basic event is equal to the unreliability of the basic event. That is,

$$\bar{a}_i = \bar{r}_i.$$

The unavailability of the K^{th} minimal cut set, expressed as $\bar{A}_K$, is the probability the K^{th} minimal cut set is in the failed state as a function of time. The unavailability of a minimal cut set is determined by this equation[12]:

$$\bar{A}_K(t) = \prod_{i=1}^{n_k} \bar{a}_i(t).$$

where n_k is the number of basic events in minimal cut set K.

The unreliability of the minimal cut set, expressed as $\bar{R}_K$, is the integral of the density of time to first failure. However, since all basic events are assumed nonrepairable, the unreliability of a minimal cut set is as follows[10]:

$$\bar{R}_K(t) = \prod_{i=1}^{n_k} \bar{r}_i(t).$$

The TOP event unavailability, $\bar{A}_T$, is the probability the TOP event is in the failed state as a function of time. A bounding approximation for $\bar{A}_T$ is[12]

$$\bar{A}_T(t) \leq \sum_{K=1}^{N} \bar{A}_K(t)$$

where N is the number of minimal cut sets.
This approximation always, but usually only slightly, overpredicts the TOP event unavailability.

The unreliability of the TOP event, $\bar{R}_T$, is bounded as follows[12]:

$$\bar{R}_T(t) \leq \sum_{K=1}^{N} \bar{R}_K(t).$$

Knowing the relative importance of failure modes and the relative importance of basic events is of value when upgrading safety systems and improving system reliability. System upgrading efforts should be directed at basic events in minimal cut sets which have the largest unavailability importance. Both unavailability and unreliability importances of minimal cut sets are obtained as a first step toward determining the unavailability and unreliability importances of the basic events.

The minimal cut set importance, $I_K(t)$, can be interpreted as the time-dependent probability the minimal cut set failure is causing the

TOP event, given the TOP event has occurred. This can be expressed as the unavailibility importance (I_K^a) or the unreliability importance (I_K^r).

To quantify, first consider the unavailability importance of minimal cut set K (I_K^a). Let

A = The event "minimal cut set K" is in the failed state. That is, all the basic events in the minimal cut set are in the failed state.

B = The event "the TOP event" is in the failed state.

Then,

$$I_K^a(t) = P(A/B) = \frac{P(A \cap B)}{P(B)} = \frac{P(A)P(B/A)}{P(B)}$$

The probability the TOP event is failed, given a minimal cut set is failed, equals unity (P(B/A)=1). Therefore,

$$I_K^a(t) = \frac{P(A)}{P(B)}$$

where

$P(A) = \bar{A}_K(t)$, the probability minimal cut set K is failed as a function of time.

$P(B) = \bar{A}_K(t)$, the probability the TOP event is failed as a function of time.

Therefore,

$$I_K^a(t) = \frac{\bar{A}_K(t)}{\bar{A}_T(t)}.$$

System improvement effort should initially be directed toward the minimal cut set with the largest values of $I_K^a(t)$.

The unavailability importance of basic event x, $i_x^a(t)$, is the time-dependent probability that basic event x is a contributor to the failure of the TOP event, given the TOP event has occurred. To quantify the unavailability importance, consider

A = The event "at least one minimal cut set containing x is failed",

B = The basic event "x is failed",

C = The event "the TOP event is failed".

Then,

$$P((A \cap B)/C) = \frac{P(A \cap B \cap C)}{P(C)} = \frac{P(A \cap B)\ P\ (C/(A \cap B))}{P(C)}.$$

Since P(C/(A ∩ B)) = 1 (the probability the TOP event is failed, given a minimal cut set is failed):

$$i_x^a(t) = \frac{P(A \cap B)}{P(C)} = \frac{P(A)P(B/A)}{P(C)}.$$

The probability that basic event x is failed, given at least one minimal cut set containing x is failed, is equal to unity (P(B/A)=1). Therefore,

$$i_x^a(t) = \frac{\sum_{K=1}^{m} \overline{A}_K(t)}{\overline{A}_T(t)}$$

or

$$i_x^a(t) = \sum_{K=1}^{m} I_K^a(t)$$

where m is the number of minimal cut sets containing x[10].

A similar derivation using the reliability term leads to another definition of importance: unreliability importance. For the cut set, the unreliability importance is as follows:

$$I_K^r(t) = \frac{\overline{R}_K(t)}{\overline{R}_T(t)},$$

and for the basic events, the unreliability importance is

$$i_x^r(t) = \frac{\sum_{K=1}^{m} \overline{R}_K(t)}{\overline{R}_T(t)},$$

or

$$i_x^r(t) = \sum_{K=1}^{m} I_K^r$$

where m is the number of minimal cut sets containing x[10].

CHAPTER 3

SYSTEMS INTERACTION ANALYSIS OF THE CLINCH RIVER BREEDER PLANT SHUTDOWN HEAT REMOVAL SYSTEM

The methodology presented in this thesis is demonstrated with an analysis of the CRBRP Shutdown Heat Removal System[13,14] (SHRS) for potential systems interactions. The SHRS performs an essential safety function by removing decay heat after shutdown. The SHRS itself is composed of several subsystems and requires the support of many other systems in the CRBRP. The importance of the heat removal function, coupled with the diversity of support systems involved, makes the SHRS an ideal candidate for a systems interaction analysis.

3.1 System Description

The SHRS removes heat generated by radioactive decay after shutdown from the CRBRP reactor core during all normal shutdown conditions and during all operational occurrences and postulated accidents.

The SHRS consists of the Main Heat Transport System (Figure 3.1) and the Direct Heat Removal System (Figure 3.2). The purpose of the Main Heat Transport System is to remove heat from the reactor core. It is composed of three identical loops that together make up the Primary Heat Transport System (PHTS) and the Intermediate Heat Transport System (IHTS). The PHTS transports heat from the reactor core to the Intermediate Heat Exchanger (IHX). Each of the three PHTS loops contains a centrifugal sodium pump, an IHX, a permanent magnet flow-meter, and a check valve. The IHTS consists of three cooling loops operating in parallel to circulate sodium from the tube side of the

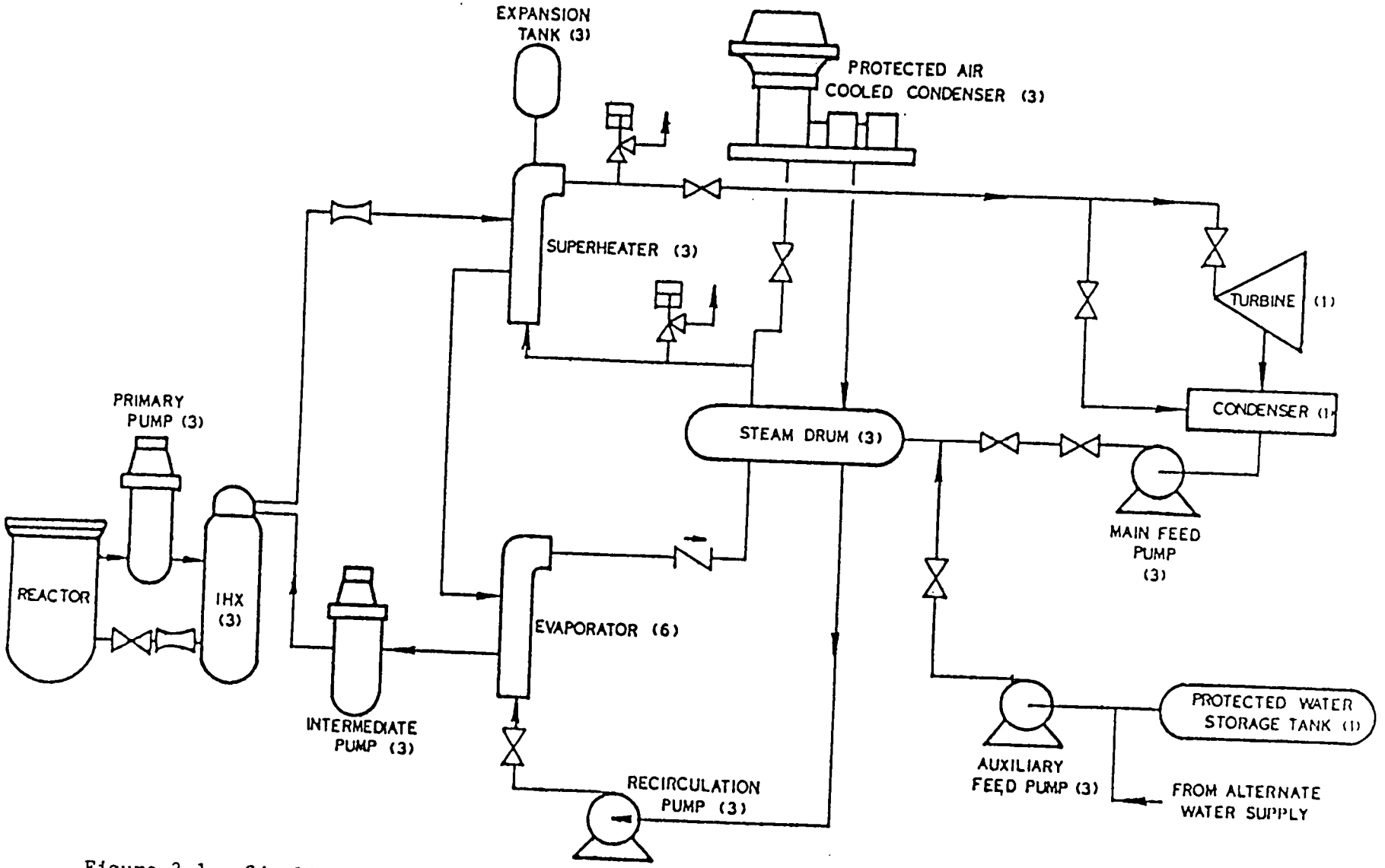


Figure 3.1. Simplified schematic of the Main Heat Transport System.

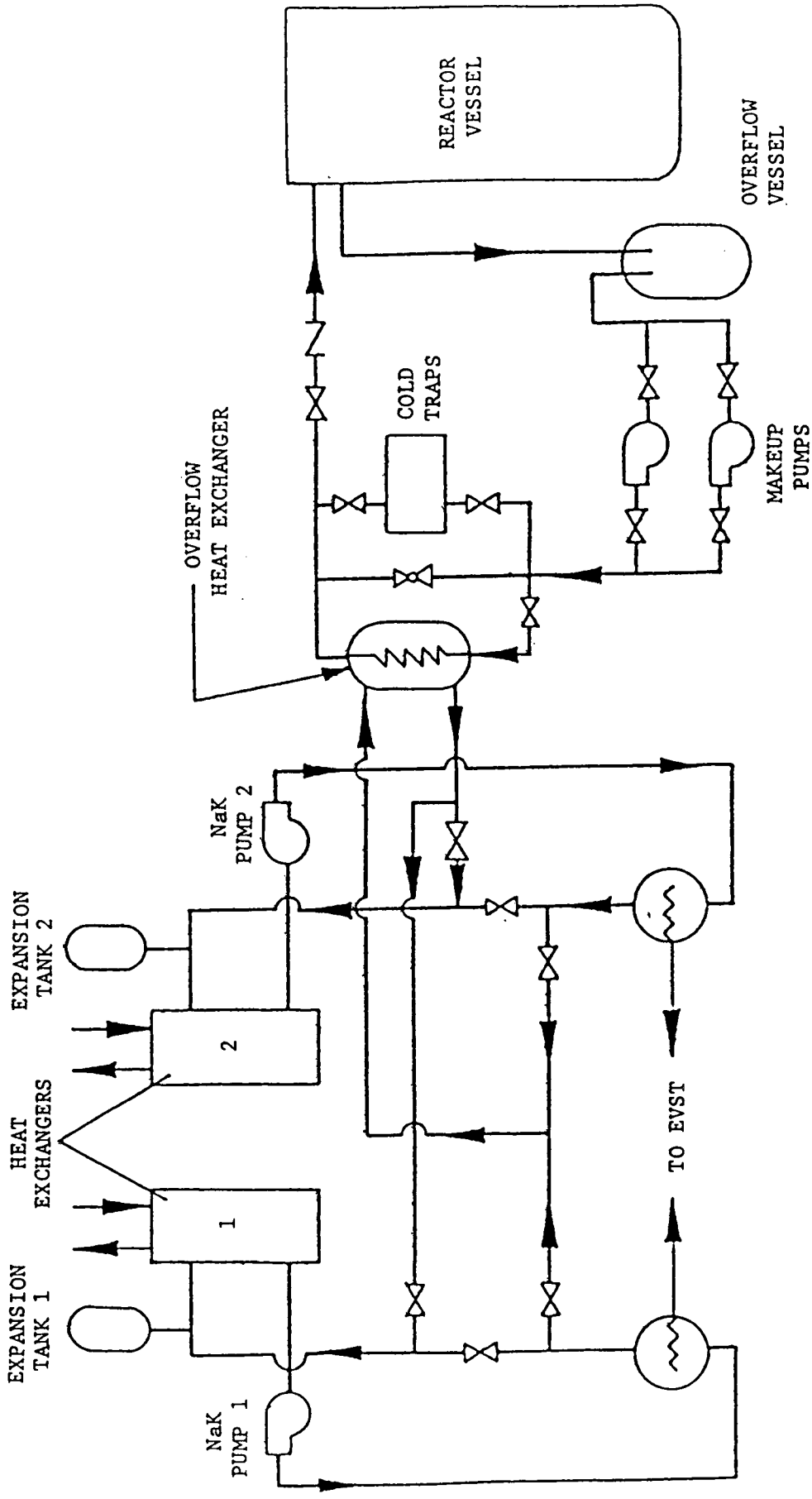


Figure 3.2. Simplified schematic of the Direct Heat Removal System.

IHXs through the steam generators and back to the IHXs. Each of the cooling loops consists of a cold leg pump, a sodium expansion tank, a permanent magnet flow-meter, and piping to transport the sodium from the IHX outlet through a superheater and two evaporators back to the IHX inlet. The Steam Generator System (SGS) extracts heat from the sodium in IHTS and transports it to a heat sink. There are three SGS loops; one for each IHTS loop. Each SGS loop consists of a steam drum, a recirculation water pump, and three steam generator modules. These steam generator modules are the evaporators and superheaters shared with the IHTS. The heat sink is either the Main Condensate/Feedwater System, used during normal plant operation, or the Steam Generator Auxiliary Heat Removal System (SGAHRS), used during off normal plant operation. The steam produced by the SGS loops is fed to the Condensate System through turbine bypass valving. Feedwater is returned from the condensor hot well by two condensate pumps and three main feedwater pumps to the three steam drums. This system is used whenever the Condensate System and offsite power are available. The offsite power is needed to power the non-safety-related condensate pumps and main feedwater pumps. SGAHRS is used whenever the Condensate/Feedwater System is unavailable. SGAHRS consists of the short term Auxiliary Feedwater System (AFWS) and the long term Protected Air Cooled Condenser System (PACC). The AFWS consists of a Protected Water Storage Tank (PWST), three pumps, and associated valves and piping. One pump is steam turbine driven. The steam is supplied by any one of the three steam drums. The other two pumps are driven by normal or emergency AC power. The objective of the pumps is to provide a supply of auxiliary

feedwater from a protected source. On a short term basis, decay heat is removed via direct steam dump to the atmosphere through vent valves at the steam drum or superheater outlets. The PWST contains a sufficient supply of water to allow venting until the PACCs become available, to allow for losses due to pipe rupture, and to provide makeup water for a thirty day period. The PACCs provide long term decay heat removal capability when SGAHRS is activated following shutdown. One PACC is connected to each steam drum. Steam rises from each steam drum by natural circulation to a PACC where it is condensed. The water is returned to the steam drum by gravity flow.

The Direct Heat Removal System (DHRS) is composed of two subsystems, the Sodium Overflow System and the Ex-Vessel Storage Tank (EVST) Cooling System. In the primary loops the Sodium Overflow System transports sodium from the reactor core to the overflow heat exchanger (OHX). The Sodium Overflow System includes a sodium overflow vessel, two electromagnetic sodium makeup pumps, the OHX, and a check valve. The OHX thermally couples the EVST Cooling System and the Sodium Overflow System. The EVST Cooling System transfers heat from the OHX to the Airblast Heat Exchangers (ABHX). The system consists of two identical cooling loops. These loops operate in parallel to transfer NaK from the shell side of the OHX through the ABHXs back to the OHX. Each loop contains an electromagnetic NaK pump, a NaK expansion tank, an EVST to for each NaK cooler, and an ABHX.

A diverse capability to transfer decay heat from the reactor core to the ultimate heat sink via natural circulation of sodium has been incorporated in the CRBRP SHRS design.

When offsite electrical power is unavailable, electrical power is supplied to SHRS components by two diesel generators and a battery system. Diesel generator A supplies power to loop 1 of the Main Heat Transport System, sodium makeup pump 1, and ABHX loop 1. Diesel generator B supplies power to loop 2 of the Main Heat Transport System, sodium makeup pump 2, and ABHX loop 2. The batteries supply power to loop 3 of the Main Heat Transport System.

3.2 Problem Definition

The SHRS failure of interest (TOP event) for this analysis is "loss of capability to provide forced convection cooling to the reactor core during shutdown given loss of offsite power." After shutdown of the reactor from 100 percent power the SHRS undergoes three distinct phases of operation. During each of these phases different systems interactions exist which further complicate the analysis.

Only Phase One of the mission is considered in this systems interaction analysis. Phase One is defined as the time period from 0 to 3 hours after shutdown. During this time either full capacity DHRS or any SGS loop venting steam are capable of removing the full decay heat load.

3.3 SHRS Functional Fault Tree

Previous work by J. J. Rooney[15] and D. J. Campbell,[16] provides the functional fault tree for the first phase of the SHRS mission. The following assumptions apply:

1. Offsite electrical power is not available.
2. The reactor is shutdown from 3-loop, 100 percent power operation.
3. Shutdown occurred as a result of a reactor scram, i.e., the control rods were inserted into the reactor core.
4. This shutdown normally trips the primary and intermediate pumps to pony motor operation.
5. Once tripped to pony motor operation, the primary and intermediate pumps will not be restarted until the end of shutdown.
6. Natural circulation of feedwater through the steam generators is sufficient for decay heat removal. No additional credit is taken for natural circulation.
7. No credit is taken for valves "failing safe."

Modifications were made to the fault tree from References 15 and 16 for the purpose of this systems interaction analysis. A systems interaction fault tree was developed by replacing each basic event in the functional fault tree with a logic OR gate. The inputs to the gate are the interfacing systems that directly interact with the removed basic event and can potentially cause its occurrence. This gives the systems interaction fault tree at the primary interface level. The same basic procedure is reapplied to this fault tree to obtain the systems interaction fault tree at the secondary interface level.

3.4 Compilation of CRBRP System Interface Tables

Appendix B provides system interface tables for forty of the CRBRP

systems. The tables were developed from interface listings provided in the system design descriptions (SDD) for the CRBRP.17 Ommitted are superfluous systems such as grounds maintenance. Each table presents the system of interest, followed by a list of systems that provide support to that system.

All basic events in the functional fault tree can be assigned to a specific CRBRP system. The system interface tables are then consulted to determine which support systems can cause the occurrence of the basic event if that support system malfunctions. Once the nonessential systems are eliminated, each of the remaining systems are examined in more detail to determine more specific information about separate trains or buses of support to the component of interest.

3.5 SHRS Systems Interaction Fault Tree

After completion of the functional fault tree, a list of pertinent systems is obtained from the interface tables. All assumptions used in construction of the functional fault tree apply to the systems interaction fault trees (Appendix C and D). For the TOP event analyzed in this study, the systems involved in the functional fault tree are the PHTS (System 51A), IHTS (System 51B), SGS (System 52), SGAHRS (System 53) and the AFWS (System 71) and the ALMS (System 81). The primary interfacing systems are obtained from the CRBRP system interface tables (Appendix B). Not all of these primary interface systems are applicable in the analysis. For example, neither the sodium fire protection system (system 26A) nor the non-sodium fire protection system (system 26B) are considered because they do not directly interact with any component in the functional fault tree. However, an inadvertent operation of the

plant fire protection system could cause the occurrence of the TOP event. This is handled better through a common cause analysis of the systems interaction fault tree. For the SHRS, there are seven systems directly involved with the operation of SHRS components at the primary and secondary interface levels. These interfaces were found from several documents[13,14,17] made available by Westinghouse. A list of interfaces with a description of each is given below.

3.5.1 Building Electrical Power System (system 12)

The Building Electrical Power System supplies all electrical power throughout the entire plant. Power is received from the power transmission system and is distributed to various plant loads via buses and motor control centers. The power system provides primary support to virtually all systems involved in this study. Not all components can fail if electric power is lost; some are "fail safe", (that is, their failure mode does not produce an adverse consequence). Information provided in SDD-12 distinguishes power sources by bus. These distinct buses are given in the systems interaction fault trees (Appendix C and D). This analysis did not progress to the next interface level of each particular power bus--the diesel generator or battery supply. Each bus considered was an essential power bus (designated Class 1E) and each received power from a diesel generator or battery. However, specific information about the power buses would be lost if replaced by its interfacing system in the fault tree. Leaving the interface level at each bus provides information on whether or not two loops were actually independent or whether a common power bus is shared. To determine whether the power buses receive power from the same supply, the power

bus identification numbers are studied. If the power bus identification number ends in "A", the bus is supplied by diesel generator A; if it ends in "B", the bus is supplied by diesel generator B; and if it ends in "C", the bus is supplied by the batteries. These identification numbers provide additional information about the SHRS. More importantly, diesel generator A supplies the power for MHTS loop 1 and some components in the DHRS, diesel generator B supplies power to MHTS loop 2 as well as some components in the DHRS, while the batteries supply power to MHTS loop 3. Consequently, what appears to be four independent heat removal paths are really only three heat removal paths.

3.5.2 Compressed Gas System (system 22)

The Compressed Gas System (CGS) is composed of four process subsystems and the instrumentation and controls needed to distribute compressed gas to service plant components and equipment as required. The four subsystems are the Service Air System, Instrument Air System, Hydrogen System and Carbon Dioxide System.

The Service Air (SA) System processes ambient air to provide compressed, oil free, dry air to be stored and distributed for use by various plant systems. This system also delivers breathable air to required stations and supplies air to the Instrument Air System.

The Instrument Air (IA) System processes air received from the SA to provide compressed, filtered, dry air to equipment which require very high quality (clean) air. Instruments, pneumatic piston and diaphragm valve operators, and air locks located in all areas of the plant, (except in the inerted cells) receive processed air from this system.

The Hydrogen (HY) System provides storage and supply of compressed hydrogen gas from stationary refillable cylinders. Hydrogen gas is supplied to the generator for cooling the generator stator core and rotating field.

The Carbon Dioxide (CX) System provides for storage of carbon dioxide in liquid form, evaporates the liquid to carbon dioxide gas and distributes the gas for purging the generator of residual hydrogen gas. Carbon dioxide in the generator prevents an explosion from occurring when the generator is opened for maintenance.

Only the instrument air subsystem is of interest for this systems interaction analysis (Figure 3.3). This subsystem interfaces with the pneumatic piston and diaphragm valve operators. Due to a recent design change, the valves in the Steam Generator System (System 52) and the Steam Generator Auxiliary Heat Removal System (System 53) have changed from pneumatic to electro/hydraulic valves. Therefore, the Compressed Gas System does not interact with any components on the primary interface levels. However, at the secondary interface level, this system interfaces with pneumatic valves in several support systems.

3.5.3 Chilled Water System (system 23)

The Chilled Water System consists of a Normal Chilled Water System (NC) and an Emergency Chilled Water System (EC). The NC and EC have redundant trains. The NC uses six horizontal spilt case centrifugal pumps each with 20 percent of full load cooling capacity and six mechanical refrigeration centrifugal water chillers each with 20 percent of full load cooling capacity. The sixth pump/chiller combination serves as standby while the other five pump/chillers operate. The five

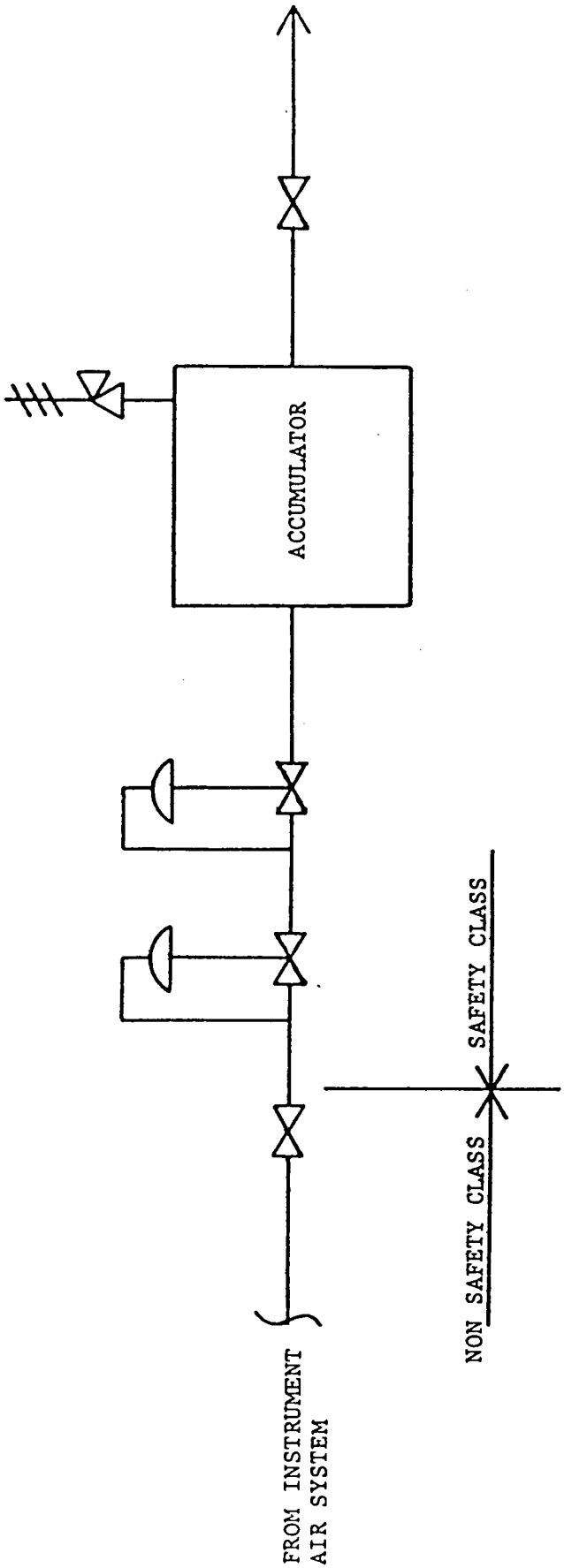


Figure 3.3. Simplified schematic of the Instrument Air System.

pump/chillers are capable of providing enough chilled water during normal plant operation at full power. The chillers are controlled manually. The number of pump/chiller combinations needed at any time depends on the chilled water system load. During normal plant operation, the chilled water system provides a heat removal function to nine CRBRP systems. However, the only SHRS system that it interacts with directly is the Auxiliary Liquid Metal System (System 81). The NC removes heat from the Primary Cold Trap NaK Cooler through a secondary coolant loop. All six NC pump/chiller combinations tie into a common header which supplies coolant to the Primary Cold Trap NaK Cooler.

The EC does not operate during normal plant operation. During normal plant operation, equipment serviced by the Emergency Chilled Water System receive chilled water from the Normal Chilled Water System through a tie connection.

Pneumatically operated valves are provided in the tie connection between the NC and EC. A loss of flow in the NC, as noted by the flow element in the tie connection between the NC and EC, actuates the emergency mode of operation (the EC).

Figures 3.4 - 3.9 show the components in the SHRS supported by the Emergency Chilled Water System. The EC receives support from the Electrical Power System and the Emergency Plant Service Water System.

3.5.4 Recirculating Gas Cooling System (system 28)

The Recirculating Gas Cooling System (RGCS) provides cooling for the primary control rod drive mechanism, primary makeup pumps, EVS sodium pumps and cold traps. It also cools the inerted cells (cells where

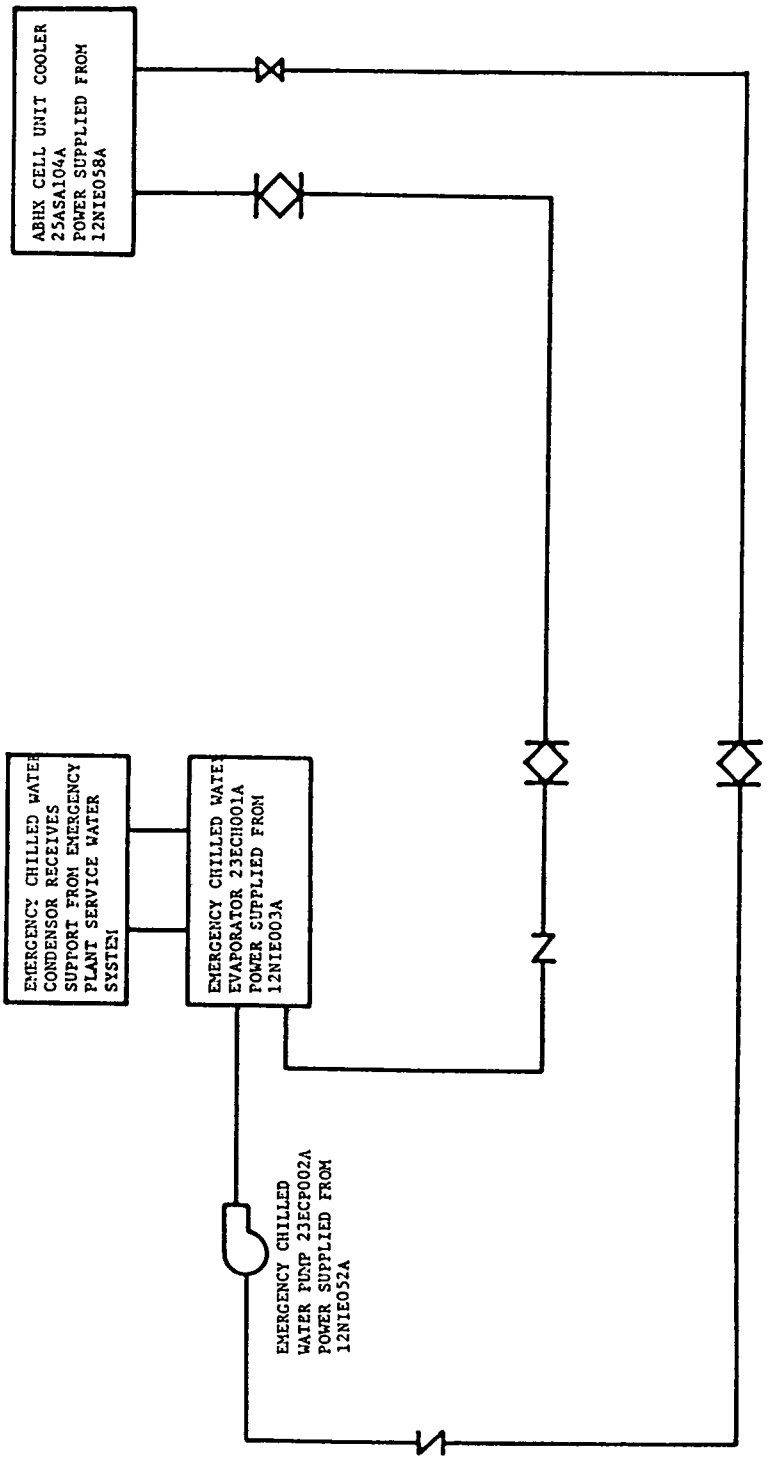


Figure 3.4. Emergency Chilled Water System to ABHX cell unit cooler A.

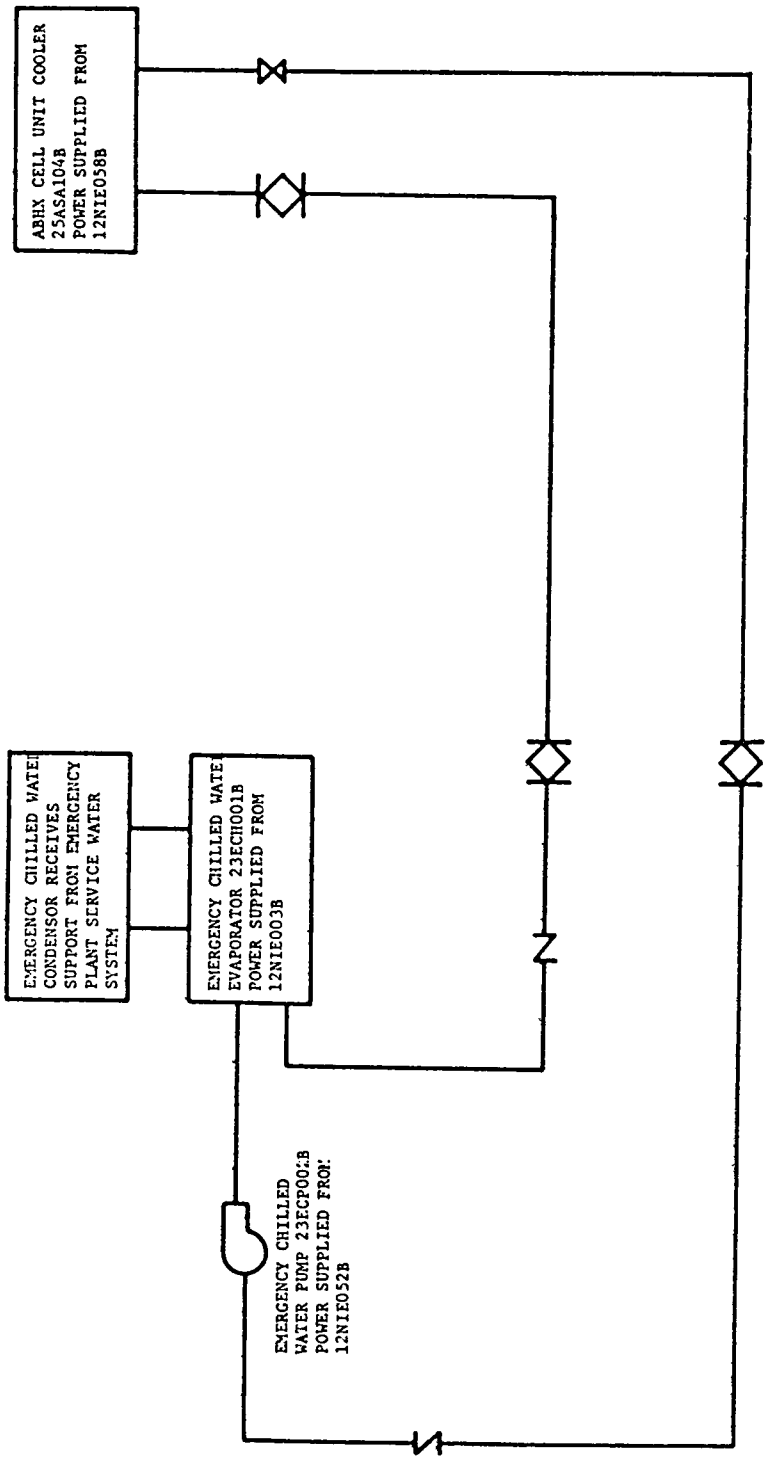


Figure 3.5. Emergency Chilled Water System to ABHX cell unit cooler B.

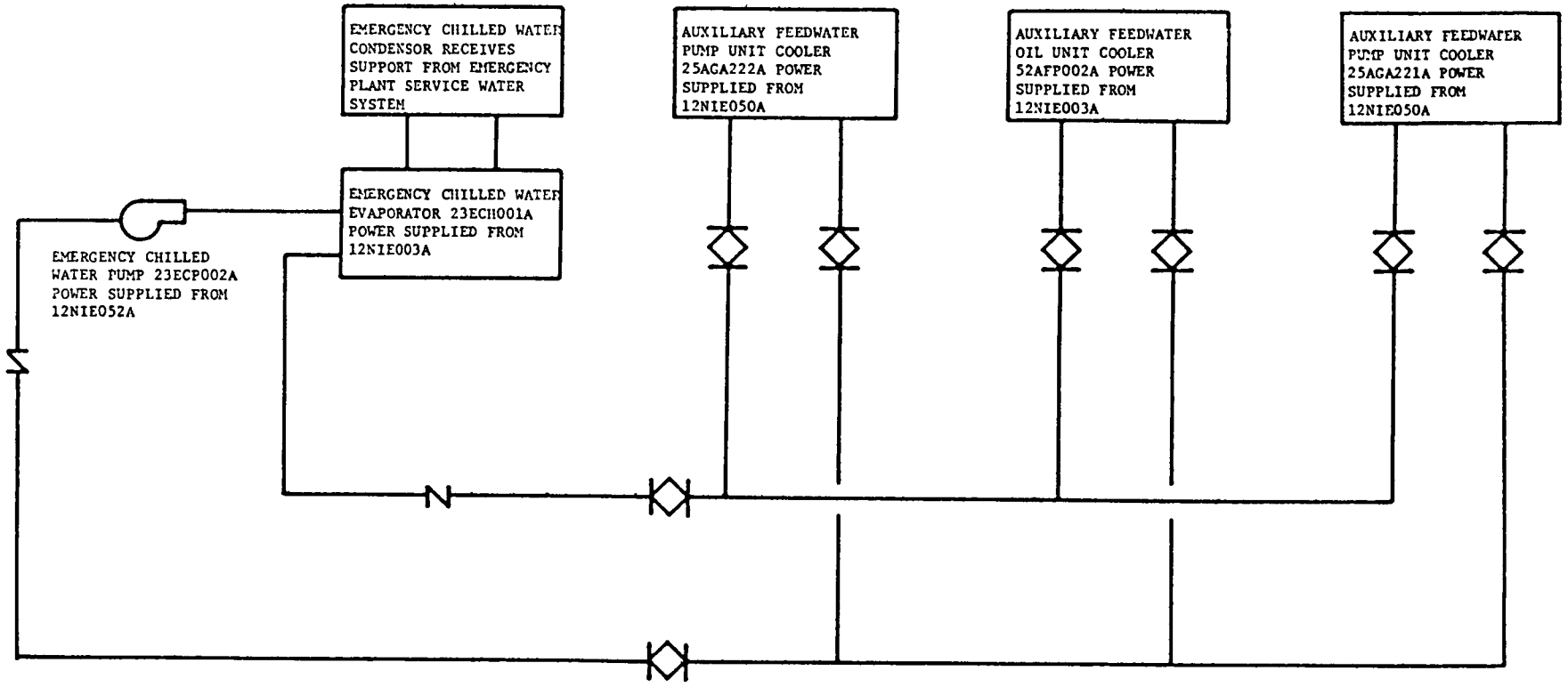


Figure 3.6. Emergency Chilled Water System to auxiliary feedwater pump A unit coolers and oil unit coolers.

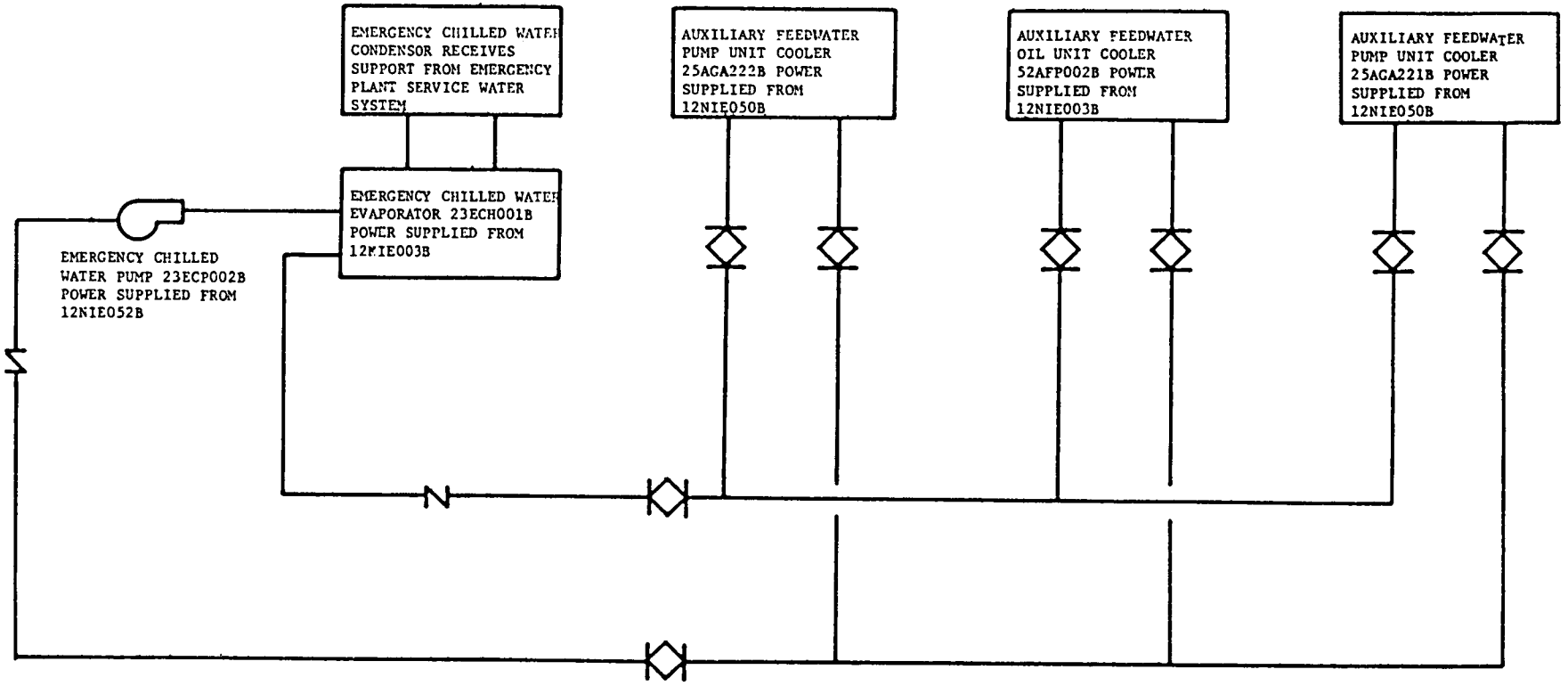


Figure 3.7. Emergency Chilled Water System to auxiliary feedwater pump B unit coolers and oil unit cooler.

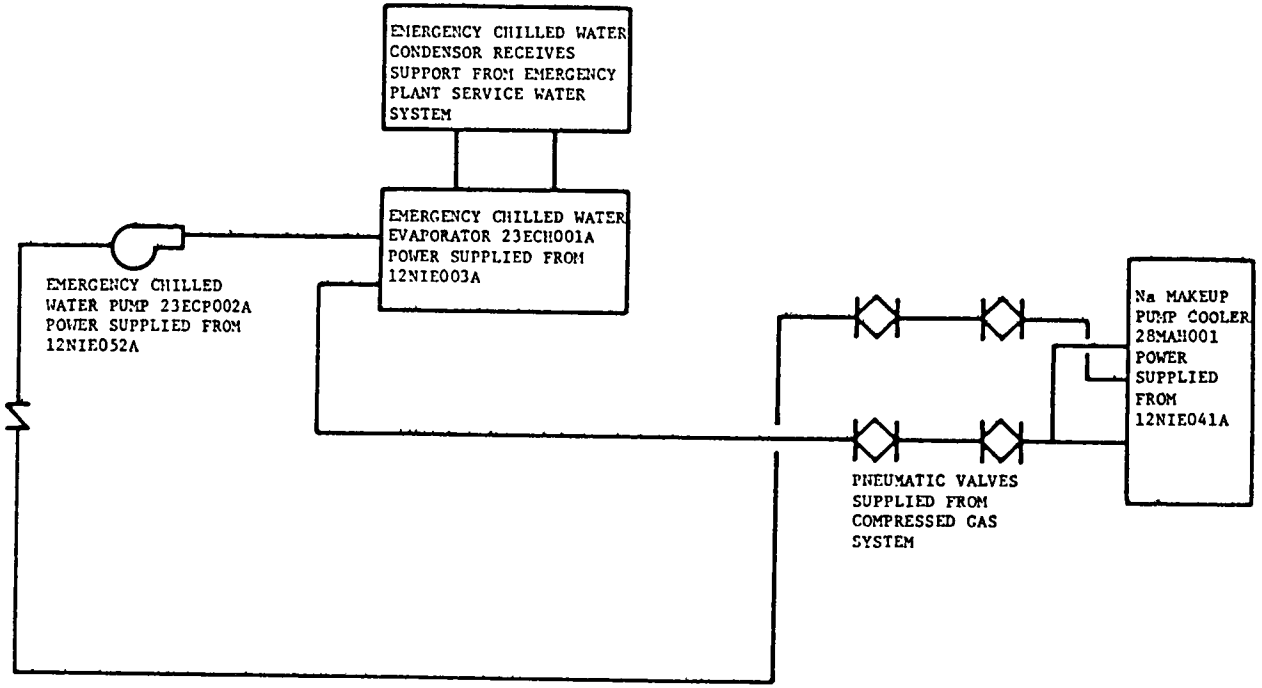


Figure 3.8. Emergency Chilled Water System to Na makeup pump A pump cooler.

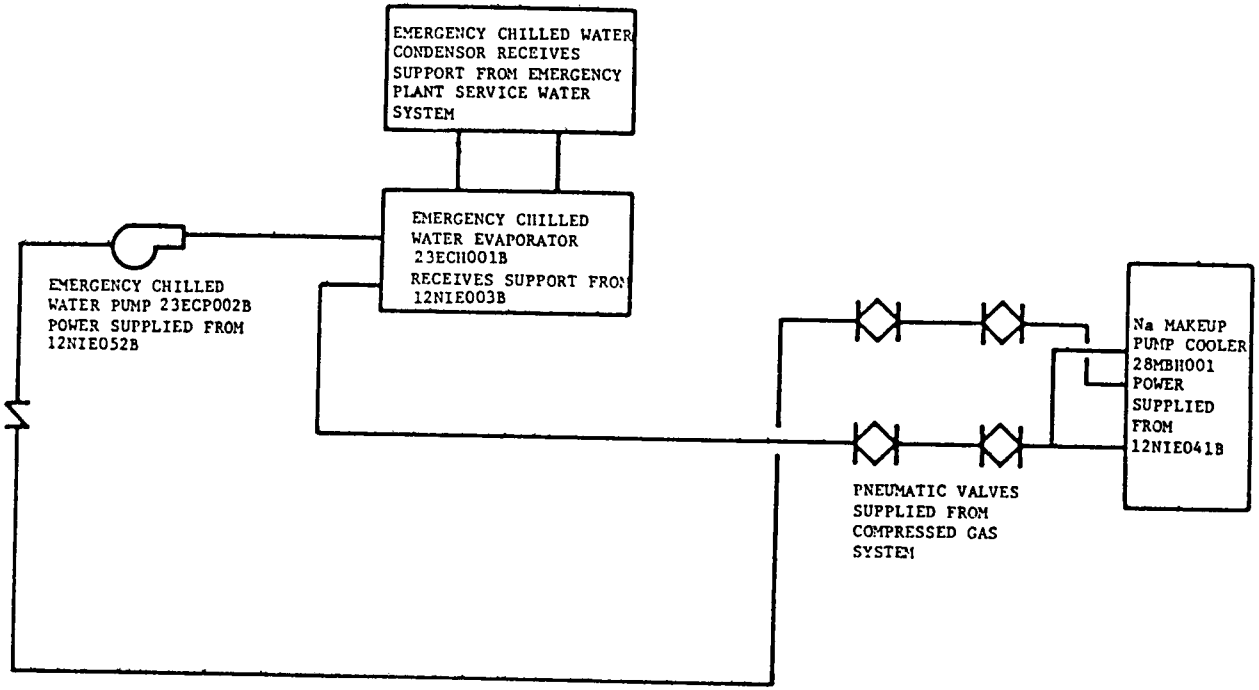


Figure 3.9. Emergency Chilled Water System to Na makeup pump B pump cooler.

sodium is present) to prevent damage to instrumentation, equipment, and cell structural concrete (see Figures 3.10 and 3.11).

The Recirculating Gas Cooling System consists of thirteen independent subsystems, eight of which are in the Reactor Containment Building (RCB) and five in the Reactor Service Building (RSB). Each subsystem consists of coolers, fans, and isolation valves connected in a closed loop to one or more of the served cells. The recirculating gas is cooled by the Normal and Emergency Chilled Water Systems. The RGCS interfaces with the Auxiliary Liquid Metal System (System 81) through the Na makeup pumps and the NaK pumps. The two sodium makeup pumps are each supplied by a separate train of the RGCS. Train 28MA of the RGCS serves the Na makeup pump Number 1. The other pump is served through train 28MB. The RGCS receives support from the Electrical Power System, the Inert Gas System, the Emergency Chilled Water System, and the Compressed Gas System.

3.5.5 Feedwater and Condensate Systems (system 71)

The Feedwater and Condensate Systems (Figure 3.12) are designed to provide a reliable source of high quality water for the steam generators during both normal operation and anticipated transient conditions. These systems are isolated from the steam generating systems when a chemistry upset occurs that could have an adverse impact on the steam generators. They are also isolated from the steam generating systems when the feedwater system is rendered inoperable. The Feedwater and Condensate Systems interface with the SHRS at the three steam drums. If there is no water supply to these steam drums, turbine-driven pump A in the SGAHRS loses its steam supply. Loss of water to the steam drums can

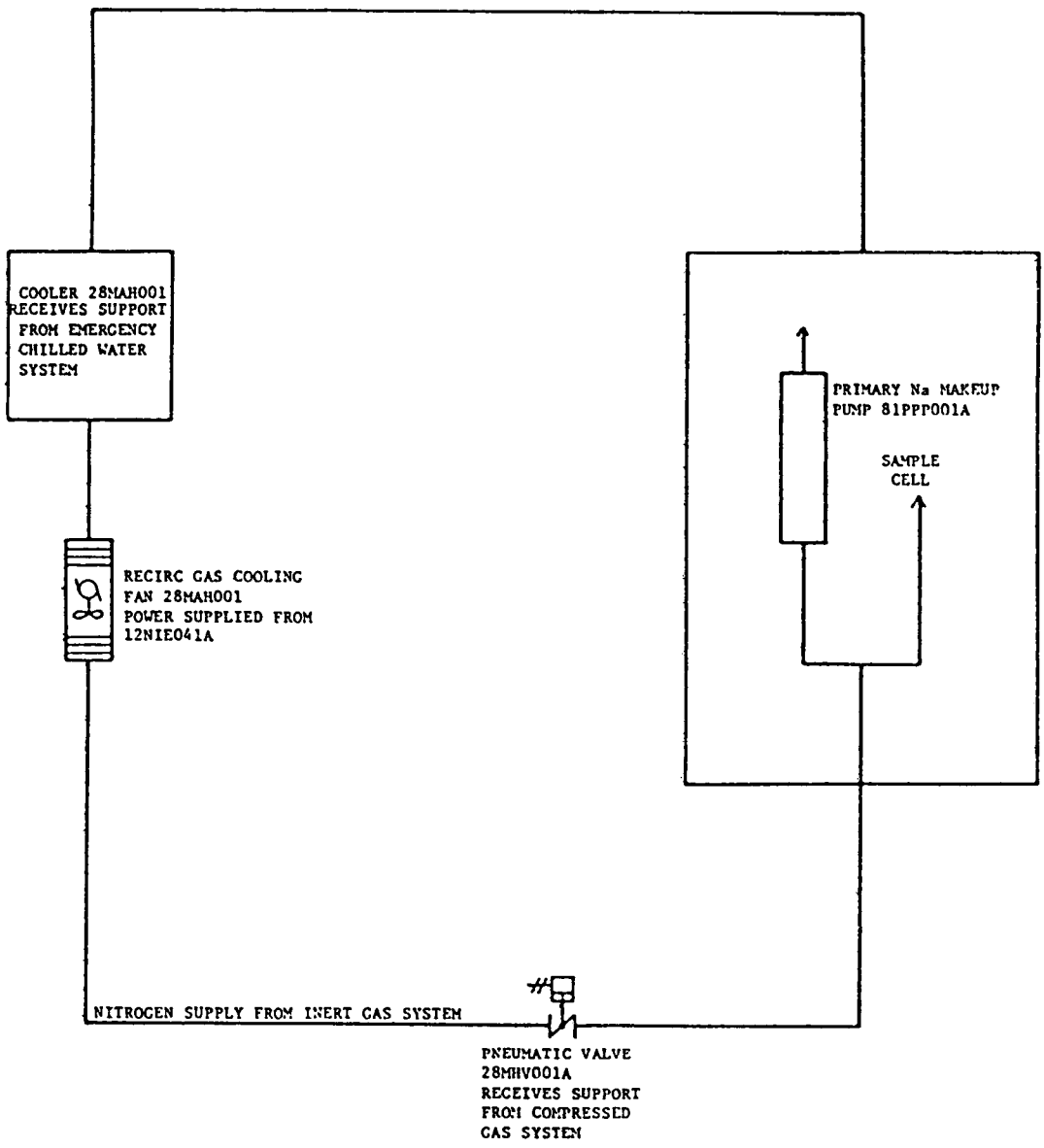


Figure 3.10. Recirculation Gas Cooling System to Na makeup pump A.

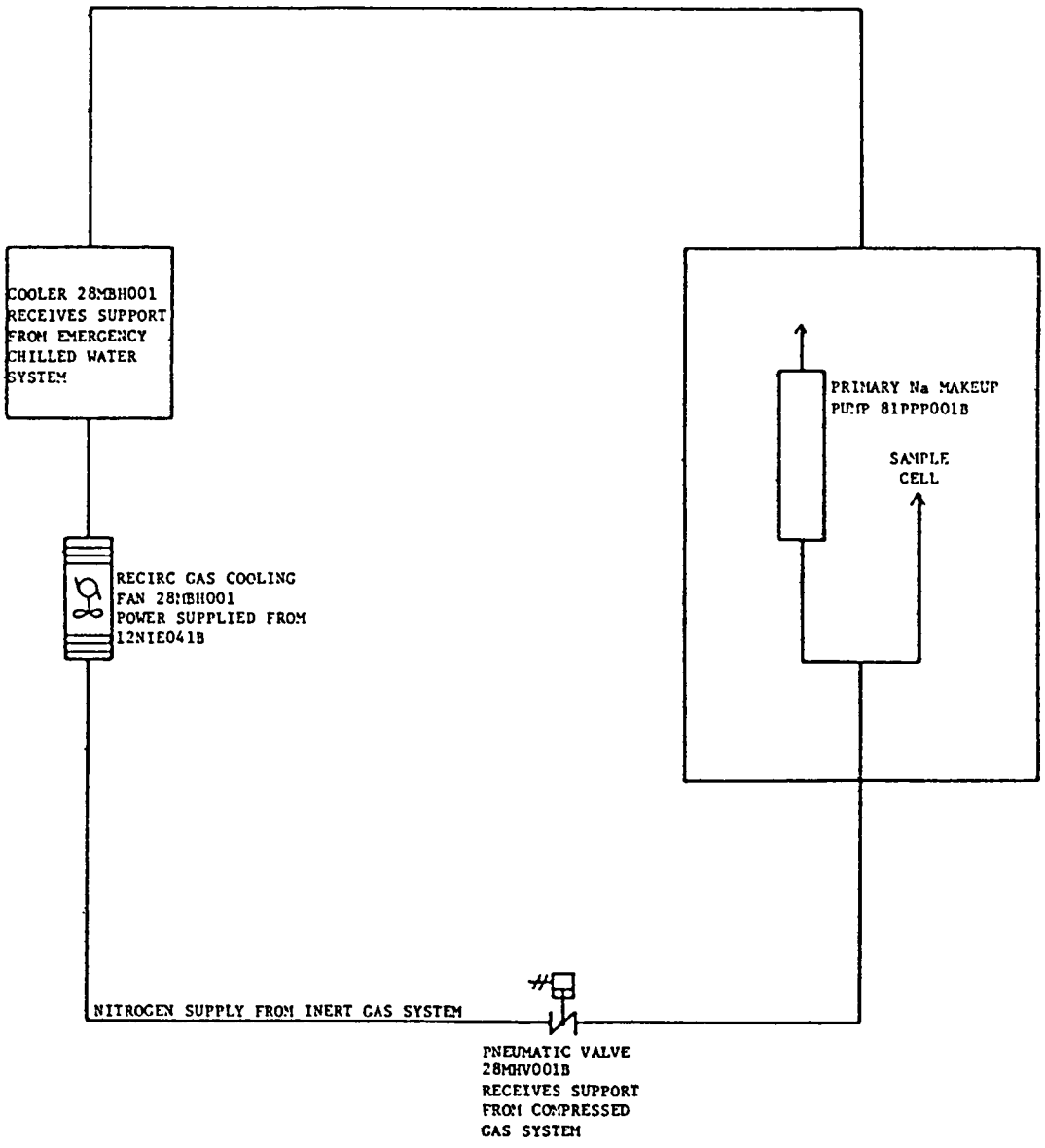


Figure 3.11. Recirculation Gas Cooling System to Na makeup pump B.

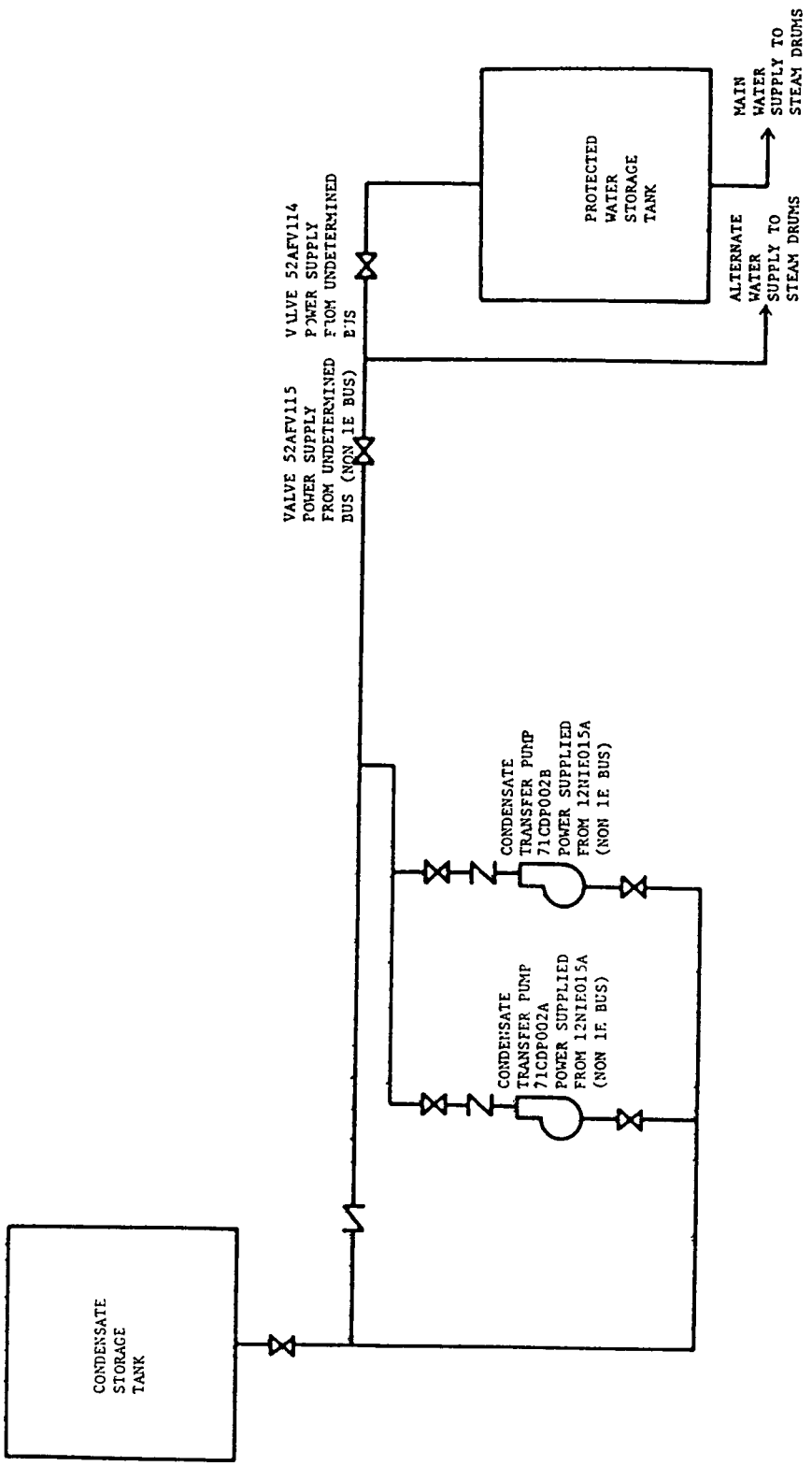


Figure 3.12. Feedwater and Condensate System to Steam Generator Auxiliary Heat Removal System.

occur if the PWST is empty and the Feedwater and Condensate Systems fail to supply feedwater. These two water sources are independent and both must fail to result in a loss of water to the steam drums. However, the Feedwater and Condensate Systems are non-safety related systems. The Condensate Storage Tank (CST) in the Feedwater System is only a backup to the Protected Water Storage Tank (PWST). Upon loss of offsite power, the motor-driven condensate transfer pumps fail. Consequently, this system is a backup system only when offsite power is available. Since this analysis assumed offsite power was unavailable, the CST was assumed to be unavailable.

3.5.6 Inert Gas Receiving and Processing System (system 82)

The Inert Gas System maintains and stores liquified and ambient gas, and delivers inert gases (of specified composition and purity at regulated flow rates and pressures) for use throughout the plant. There are four subsystems: the Argon Distribution Subsystem, the Radioactive Argon Processing Subsystem, the Nitrogen Distribution Subsystem, and the Cell Atmosphere Processing Subsystem. The only subsystem of interest for the SHRS systems interaction analysis is the Nitrogen Distribution Subsystem (Figure 3.13). Nitrogen gas is provided for inerting the cells, valve actuation in inerted cells, and cover gas for control and mitigation of sodium/water reactions. Therefore, this subsystem interfaces with the pneumatic valves in the DHRS and the cells for which coolant is provided. Valves supplied by this system were not considered to be "fail safe." Operating experience from light water reactors (LWRs) show that pneumatically operated valves may not revert to their

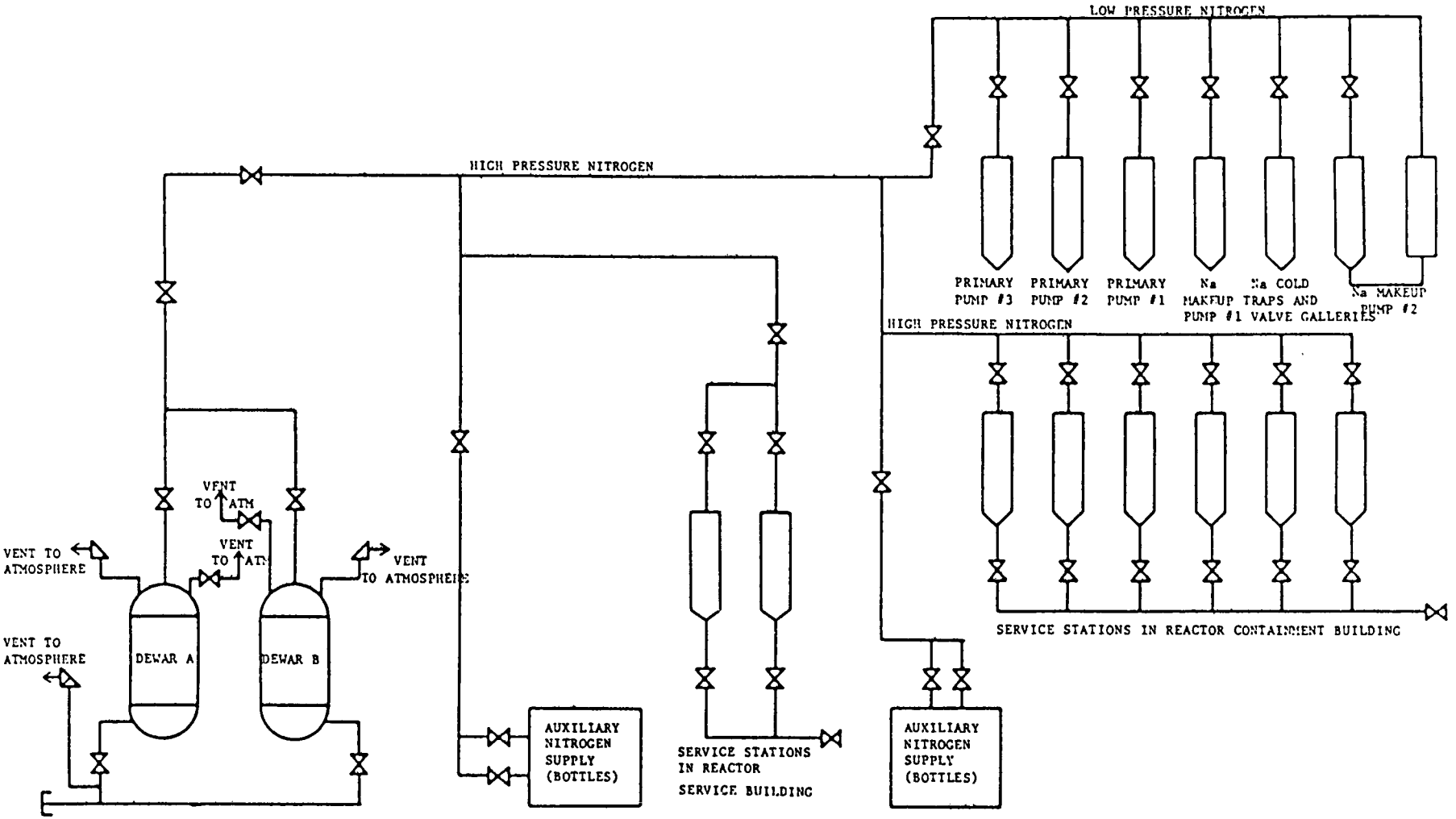


Figure 3.13. Inert Gas System to primary pumps, Na makeup pumps, RCB ans RSB service stations, and pneumatic valves ininerted cells.

"fail safe" position when the instrument air header slowly depressurizes.[18] A slow leak not only renders the instrument air system inoperable, but may bleed air out of the accumulators. Data have also shown that events involving low nitrogen pressure were caused by excessive leakage from the pneumatic system coupled with a limited supply of bottled nitrogen. Because these nitrogen operated components are normally supplied continously from plant compressors even when the plant is shutdown, the lack of effectiveness of the pneumatic system and the accumulators may not be discovered unless the plant experiences a "loss-of-air" event or unless the normal supply to the accumulators is deliberately interrupted.[19] Consequently, the inoperability of a valve may not be determined until the valves operation is demanded.

3.5.7 Plant Service Water System (system 75)

The Plant Service Water System consists of a normal and an emergency system. The Normal Plant Service Water (NPSW) System is non-safety class and therefore not used during a loss of offsite power. The Emergency Plant Service Water (EPSW) System provides sufficient cooling water during a loss of offsite power or a loss of the Normal Plant Service Water System during normal operation. This system consists of two 100 percent capacity, fully redundant cooling loops. Each cooling loop includes one circulating pump, one makeup pump, one emergency cooling tower, and associated piping, valves, instrumentation and controls (Figure 3.14).

The Emergency Plant Service Water System (EPSW) supplies cooling water to the diesel generators and the emergency chiller condensers.

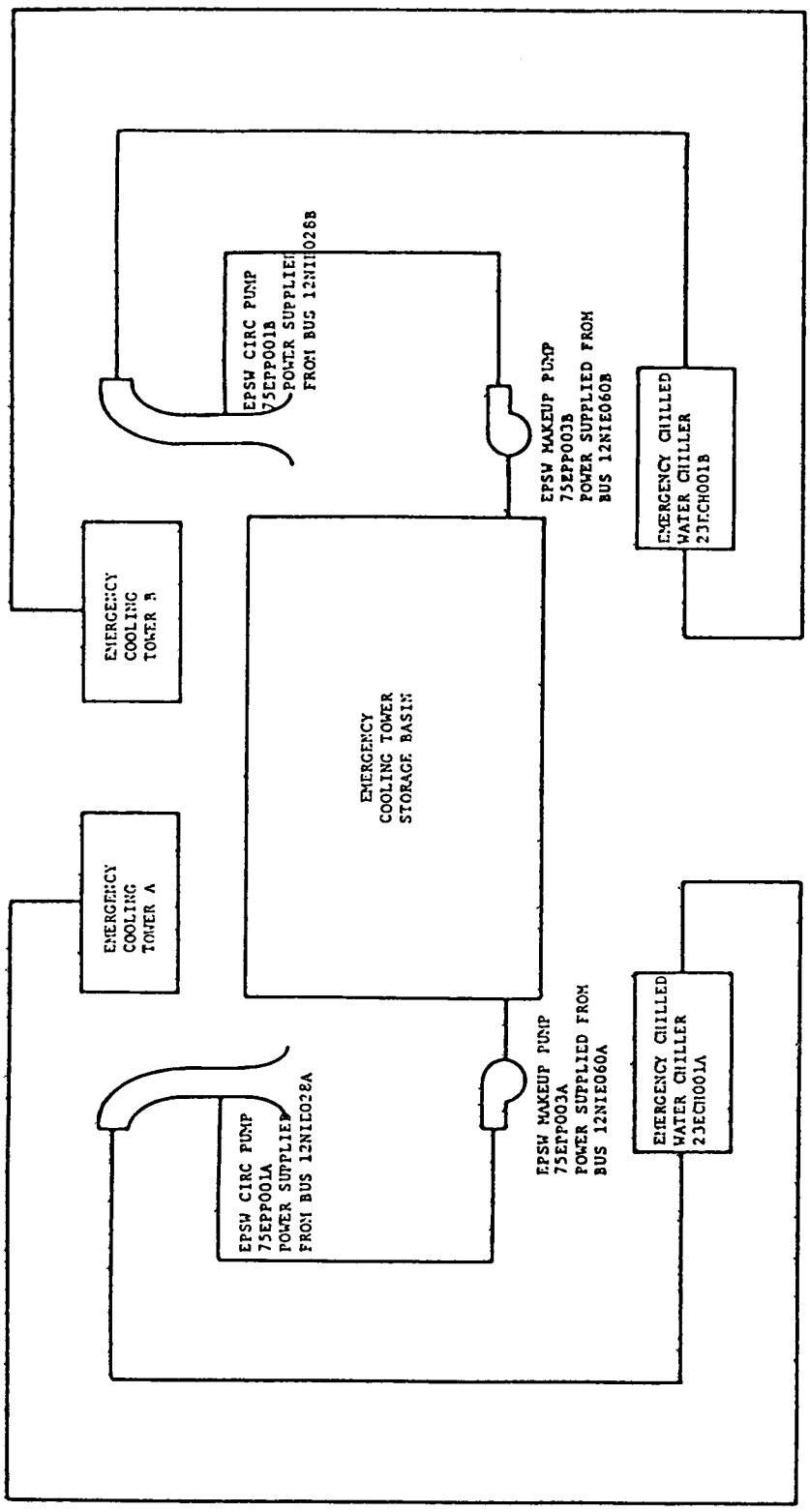


Figure 3.14. Emergency Plant Service Water System to Emergency Chilled Water System.

Figure 3.14 does not show the diesel generators since they were not included in this analysis. The EPSW pumps take suction from the emergency cooling tower operating basins. The cooling water is transferred from the common storage basin to the redundant operating basins to compensate for evaporative and drift losses from the towers.

Cooled water from the emergency cooling tower operating basins is pumped to the emergency loads (diesel generators and chillers). Afterwards, the warm water is returned to the emergency cooling towers. The EPSW also provides water to the Fire Protection System. However, this analysis only considers the support this system provides to the Emergency Chilled Water System. The EPSW receives support from the Electric Power System.

CHAPTER 4

RESULTS

The results of this study are both qualitative and quantitative. The qualitative results show that the CRBRP SHRS is not as redundant as the general system configuration indicates or as previous analyses have indicated[15,16] since several apparently redundant subsystems share support systems. The quantitative results show how the unavailability importance of support system basic events (components) increases at each interface level.

4.1 Qualitative Results

The qualitative results of the CRBRP SHRS were obtained by using the PREP computer code[9] for analyzing the functional fault tree and the systems interaction fault trees at the primary and secondary interface levels. The results for each fault tree were first reviewed separately and then compared to each other. Consequently, it was observed how the failure of interest occurred through purely functional failures, through a combination of functional and system failures, and finally through purely system interaction failures. Appendix E provides the logic model chararcter identification codes for deciphering the tables containing a list of the two- and three-event minimal cut sets for each fault tree (Appendicies F, G, and H).

A dependency between the Primary Heat Transport System and the Direct Heat Removal System has been long known--and is verified by this study. For heat removal by the DHRS, sodium mixing in the reactor core

is necessary, and all three of the Primary Heat Transport System loops must be in operation to provide this mixing (during Phase 1). Therefore, simultaneous failure of all three primary pony motors leads to the failure of the SHRS (and is therefore a failure mode) when natural circulation is neglected. Only one failure mode (minimal cut set) with fewer than three component failures has previously been reported. At the functional and primary interface levels, this is still the case. However, the analysis at the secondary interface level reveals two additional failure modes with fewer than three component failures. Some cut sets at the secondary interface level of analysis were reduced to smaller cut sets due to the dependency of redundant subsystems that share support systems. Table 4.1 shows the three two-event minimal cut sets, and how two of these cut sets were reduced to two-event minimal cut sets due to the dependency of support systems.

The only two-event minimal cut set observed from the functional and primary interface levels is the rupturing of the reactor vessel and rupturing of the reactor guard vessel. This is an extremely unlikely event and the probability of both ruptures occurring simultaneously is estimated at 3.5×10^{-15} for a 40 year plant life. Two additional two-event minimal cut sets are identified from the secondary interface level. From the functional fault tree, the two additional two-event minimal cut sets appear to be five-event minimal cut sets. At the functional level, the occurrence of the following events will cause the TOP event--loss of forced convection cooling to the reactor core:

Table 4.1 Two event minimal cut sets for the CRBRP SHRS

FUNCTIONAL INTERFACE LEVEL	PRIMARY INTERFACE LEVEL	SECONDARY INTERFACE LEVEL
RUPTURE OF REACTOR VESSEL	RUPTURE OF REACTOR VESSEL	RUPTURE OF REACTOR VESSEL
RUPTURE OF REACTOR GUARD VESSEL	RUPTURE OF REACTOR GUARD VESSEL	RUPTURE OF REACTOR GUARD VESSEL
TURBINE DRIVEN AUXILIARY FEEDWATER PUMP FAILS OFF	TURBINE DRIVEN AUXILIARY FEEDWATER PUMP FAILS OFF	TURBINE DRIVEN AUXILIARY FEEDWATER PUMP FAILS OFF
AUXILIARY FEEDWATER PUMP B FAILS OFF ABHX 1 FAILS OFF	⇒ EMERGENCY CHILLED WATER TRAIN A FAILS	⇒ EMERGENCY PLANT SERVICE WATER COOLING TOWER BASIN RUPTURES
AUXILIARY FEEDWATER PUMP C FAILS OFF ABHX 2 FAILS OFF	⇒ EMERGENCY CHILLED WATER TRAIN B FAILS	
TURBINE DRIVE TO AUXILIARY FEEDWATER PUMP FAILS OFF	TURBINE DRIVE TO AUXILIARY FEEDWATER PUMP FAILS OFF	TURBINE DRIVE TO AUXILIARY FEEDWATER PUMP FAILS OFF
AUXILIARY FEEDWATER PUMP B FAILS OFF ABHX 1 FAILS OFF	⇒ EMERGENCY CHILLED WATER TRAIN A FAILS	⇒ EMERGENCY PLANT SERVICE WATER COOLING TOWER BASIN RUPTURES
AUXILIARY FEEDWATER PUMP C FAILS OFF ABHX 2 FAILS OFF	⇒ EMERGENCY CHILLED WATER TRAIN B FAILS	

1. Turbine driven auxiliary feedwater pump A fails off,
2. Auxiliary feedwater pump B fails off,
3. Auxiliary feedwater pump C fails off,
4. ABHX 1 fails off, and
5. ABHX 2 fails off.

When considering support system interactions, this cut set shrinks from a five-event minimal cut set to a two-event minimal cut set. First, consider how the above five failures will cause the TOP event to occur. The Steam Generator Auxiliary Heat Removal System (SGAHRS) supplies water to all three steam drums in order for the steam to be vented to the atmosphere (and hence decay heat). The venting of steam from one steam drum is capable of providing enough forced convection cooling to remove the decay heat. One way to lose forced convection cooling in all three primary loops is to lose the water supply to all three steam drums. Two trains supply the water: one contains a turbine driven feedwater pump, the other contains two motor driven feedwater pumps (numbers 1, 2, and 3 above). Hence, failure to provide a water supply to the steam drums consists of the failure of the turbine driven pump (pump A), and the failure of both motor driven pumps (pump B and pump C). These three failures result in a loss of forced convection cooling to the reactor core from all three primary loops. However, as long as a primary pony motor is available to provide sodium mixing, the DHRS is capable of removing decay heat. The decay heat can be removed via either Airblast Heat Exchanger (ABHX). Hence, the loss of both ABHXs will render the DHRS incapable of providing adequate forced convection cooling of the reactor core (failure of ABHX 1 and ABHX 2).

Now, consider the systems interactions at the primary interface level. With the failure of the turbine driven auxiliary feedwater pump or the failure of the turbine drive to that pump, one of the loops for providing water to the steam drums is lost (number 1 in example). Next, consider the Emergency Chilled Water System and its two redundant loops. Each loop provides chilled water to cool one of the motor driven auxiliary feedwater pumps' cell and the pumps' oil unit cooler. Each Emergency Chilled Water System loop also provides coolant to an ABHX cell unit cooler. The loss of both chilled water loops will result in the loss of the feedwater pumps (numbers 2 and 3) and the ABHXs (numbers 4 and 5). A delay time is involved before the components will fail due to overheating. However, this analysis assumed the delay time to be zero. When consideration is given to systems interacting at the primary interface level, the five-event minimal cut set shrinks to a three-event minimal cut set. The previously unrecognized three-event minimal cut set is:

A. Turbine driven auxiliary feedwater pump A fails off,

B. ECW train A fails, and

C. ECW train B fails.

When proceeding to the secondary interface level in this systems interaction analysis, it was determined that both trains of the Emergency Chilled Water System received their water supply from the Emergency Plant Service Water System (EPSW). At first, it appears that the redundant EPSW trains insure a water supply to the redundant ECW

trains. Yet, the EPSW trains draw their water supply from a common source--the EPSW cooling tower basin. Consequently, the failure of the cooling tower basin will result in the failure of both EPSW trains. This will cause the failure of both ECW trains. The three-event minimal cut set has now been reduced to a two-event minimal cut set:

- Turbine driven auxiliary feedwater pump A fails off, and
- EPSW cooling tower basin ruptures.

Therefore, the systems interaction analysis has shown a greater dependency between systems than previously realized. The analysis reduced larger minimal cut sets as observed from a functional analysis (this example--five event minimal cut set) to a smaller minimal cut set (two-event minimal cut set).

This study also identified additional three-event minimal cut sets that were also previously unrecognized (see Table 4.2). All failures in the functional level of analysis are also identified in the primary and secondary interface levels since they are basic component failures. The majority of the additional three-event minimal cut sets identified from the primary and secondary interface levels involved at least one power bus.

In order to explain the plant's dependency on electric power, the configuration of the SHRS must be considered. The SHRS consists of four heat removal paths--the three MHTS loops and the DHRS. The transfer of decay heat is possible through all three MHTS loops operating or the DHRS operating with at least one PHTS primary pony motor operating. Note that MHTS loop 1 is supplied power by diesel generator A, MHTS loop

Table 4.2 Qualitative results of the CRBRP SHRS systems interaction analysis

QUALITATIVE RESULTS FROM THE FUNCTIONAL FAULT TREE	QULAITATIVE RESULTS FROM THE SYSTEMS INTERACTIONS FAULT TREE	
	PRIMARY LEVEL	SECONDARY LEVEL
• 1 DOUBLE FAILURE POINT	• THE SAME DOUBLE FAILURE POINT	• THE SAME DOUBLE FAILURE POINT
• 38 TRIPLE FAILURE POINTS	• THE SAME 38 TRIPLE FAILURE POINTS	• THE SAME 38 TRIPLE FAILURE POINTS
	• AN ADDITIONAL 25 TRIPLE POINTS	• THE SAME 25 TRIPLE FAILURE POINTS
		• 2 ADDITIONAL DOUBLE FAILURE POINTS
		• AN ADDITIONAL 67 TRIPLE FAILURE POINTS

2 is supplied power by diesel generator B, and MHTS loop 3 is supplied power from the batteries. In addition, diesel generator A suplies power to the DHRS (specifically ABHX loop 1) while diesel generator B also supplies power to the DHRS (specifically ABHX loop 2). This shows the coupling between the MHTS and DHRS through the electric power system. As a result, many of the newly identified three-event minimal cut sets involve the failure of at least one power bus.

4.2 Quantitative Results

The number of three event minimal cut sets increased as the analysis proceeded from the functional level, to the primary interface level, to the secondary interface level. This step in the analysis determined the unavailability importance of each basic event for each interface level. The failure rate data for each component is given in Appendix I. The quantitative results were determined using the SPOCUS computer program[10] for each fault tree. From this computer program, the unavailability importance for each component at the different interface levels was determined. The components were all ranked with respect to other components in their particular interface level. In general, a component with a high importance at the functional interface level was not as important at the primary interface level (see Figures J-1, J-2, and J-3). The components overall importance decreased even further when considering the secondary interface level. This is due to the increased dependency on electric power. Table 4.3 shows the most important components at each level of analysis.

The most important components at the functional level were the primary pony motors for all three loops (Figure J-1, J-2, and J-3).

Table 4.3 Unavailability importance of the most important basic events in the CRBRP SHRS systems interaction analysis

INTERFACE LEVEL	BASIC EVENT	UNAVAILABILITY IMPORTANCE (AT 3 HOURS)
FUNCTIONAL	PRIMARY LOOP 1 PONY MOTOR	1.00×10^{-2}
	PRIMARY LOOP 2 PONY MOTOR	1.00×10^{-2}
	PRIMARY LOOP 3 PONY MOTOR	1.00×10^{-2}
PRIMARY	POWER BUS 12NIE050A	9.00×10^{-2}
	POWER BUS 12NIE050B	9.00×10^{-2}
	POWER BUS 12NIE044C	1.00×10^{-2}
SECONDARY	POWER BUS 12NIE003A	5.00×10^{-2}
	POWER BUS 12NIE052A	5.00×10^{-2}
	POWER BUS 12NIE003B	7.50×10^{-2}
	POWER BUS 12NIE052B	7.50×10^{-2}
	POWER BUS 12NIE060A	8.00×10^{-2}
	POWER BUS 12NIE060B	7.75×10^{-2}
	POWER BUS 12NIE028B	7.75×10^{-2}
	POWER BUS 12NIE028A	8.85×10^{-2}
	AUXILIARY FEEDWATER PUMP TURBINE DRIVE	1.50×10^{-1}
	TRUBINE DRIVEN AUXILIARY FEEDWATER PUMP	7.00×10^{-2}

These pony motors are important due to the requirement that sodium mixing be available for the successful operation of the DHRS. These pumps provide the sodium mixing for the MHTS.

The most important components at the primary interface level were buses 12N1E050A, 12N1E050B, and 12N1E044C. These buses supply power to the primary pony motors in MHTS loops 1, 2 and 3 (Figures J-4 and J-5).

Ten components in the secondary interface level had high importance rankings (Figures J-6 through J-12). The components included

- eight power buses,
- the turbine drive to auxiliary feedwater pump A, and
- the turbine driven auxiliary feedwater pump A.

Again, the plant's dependence on electric power is observed.

The turbine drive to the auxiliary feedwater pump and the turbine driven auxiliary feedwater pump itself also have high importances. The turbine driven auxiliary feedwater pump provides the water supply to the steam drums. The water is supplied from the CST or the PWST, both of which have relatively high importances.

The relative rankings of the components could be different if credit were taken for natural circulation of sodium. A study considering natural circulation has been performed.[20] The diesel generators and the auxiliary feedwater pumps still received high importance rankings (at the functional interface level).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Systems interaction analyses as described in this report should be used extensively in the analysis of the nuclear reactor plant safety systems. The example analysis of the CRBRP SHRS reported here demonstrates the applicablity and importance of this technique. Since the reliability of several safety systems can be degraded due to single support system failures, the interaction of support systems to safety systems should be studied in detail.

This analysis has also shown how a systems interaction anlaysis identifies previously unrecognized minimal cut sets. For example, the functional interface level identified

- one double-failure point, and
- thirty-eight triple-failure points.

The primary interface level identified

- the same double-failure point,
- the same 38 triple-failure points, and
- an additional 25 triple-failure points.

The secondary interface level identified

- the same double-failure point,
- the same 38 triple-failure points,
- an additional 67 triple-failure points, and
- 2 additional double-failure points.

The previously unrecongnized triple-failure points are due mainly to power bus failures. This shows the CRBRPs dependence on electric power.

The unreliability and unavailability importances tell which events are most likely to contribute to the occurrence of the TOP event if it occurs. The component determined to be important at one level was not necessarily important at another. In general, the importance of components tended to decrease as the transformation progressed from the functional fault tree, to the primary interface level, to the secondary interface level. Again, this was due to the large dependency on electric power.

A complete systems interaction analysis of the CRBRP SHRS would involve performing three tasks. The first task would be to consider natural convection cooling of the reactor core when performing the systems interaction analysis even though credit for natural convection cooling cannot be considered during licensing. The second task would be to consider human interactions--that is, perform a human factors analysis. Lastly, a common cause analysis should be performed in conjuction with the systems interaction analysis. Certain systems not considered in this analysis (e.g., the Fire Suppression System) would then become actors. The performance of these three tasks would further aid in the development of systems interaction analyses.

In conclusion, a systems interaction analysis should be performed as a standard analysis. This is due to the minimal cut sets no longer being minimal. This analysis has shown how two five-event minimal cut sets from the functional analysis turned out to be two-event minimal cut

sets. However, this analysis has also shown the well thought out design of the Clinch River Breeder Reactor since the additional two-event minimal cut sets identified by this analysis have a probability of occurring simultaneously of about 1×10^{-8} for a 40 year plant life. Additionally, the design is considered to be well thought out since no one-event minimal cut sets were identified.

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19. U.S. Nuclear Regulatory Commission, Office of Inspection and Enforcement, IE Information Notice No. 82-45, November 19, 1982.

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APPENDICIES

APPENDIX A

CRBRP SHUTDOWN HEAT REMOVAL SYSTEM

FUNCTIONAL FAULT TREE

CRBRP SHUTDOWN HEAT REMOVAL SYSTEM FUNCTIONAL FAULT TREE

The CRBRP SHRS logic models were developed in the fault tree format. A fault tree is a graphical representation of the failure logic of a system to a particular TOP event.

The logic model for the CRBRP SHRS at the functional level is presented in Figure A.1.

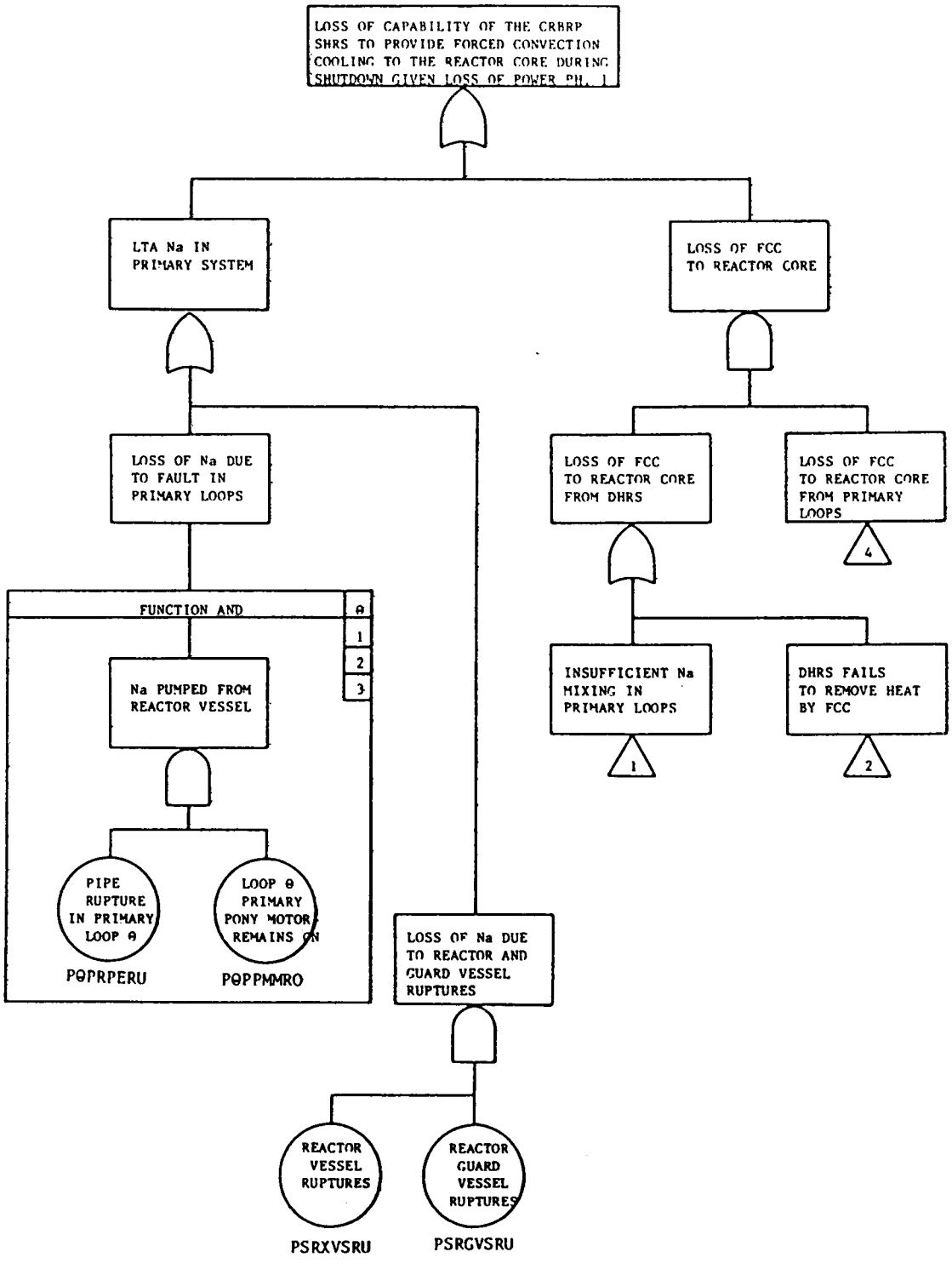


Figure A.1. CRBRP Shutdown Heat Removal System functional fault tree.

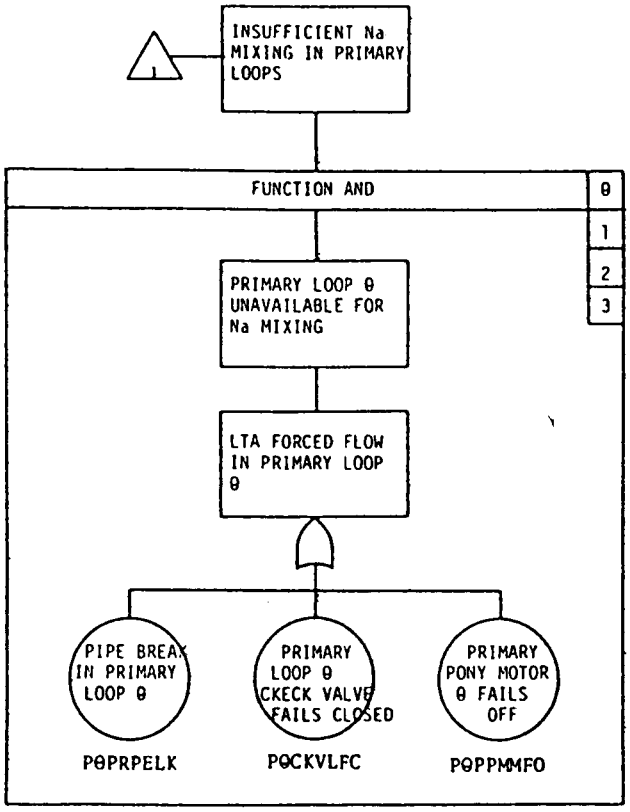


Figure A.1. (continued).

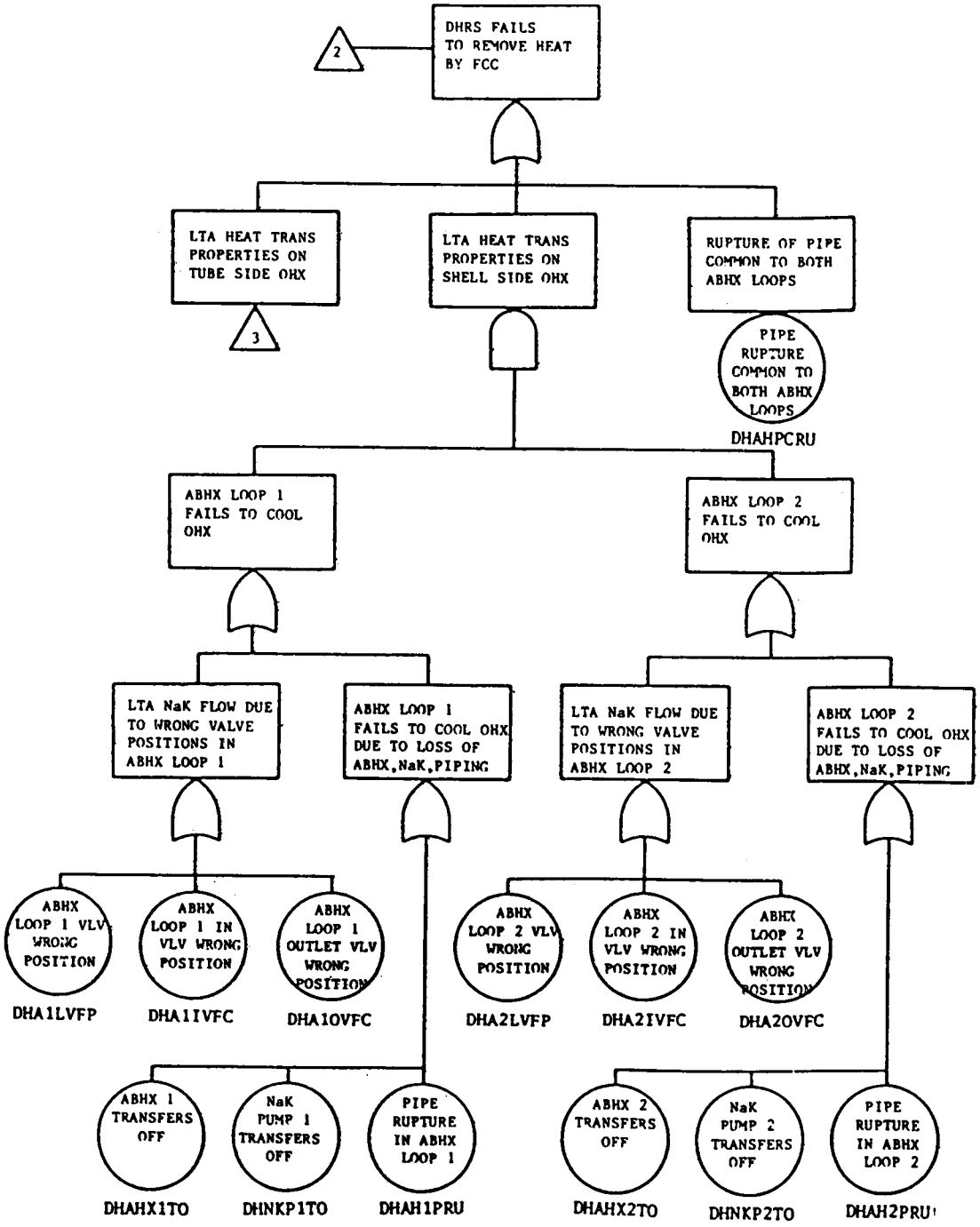


Figure A.1. (continued).

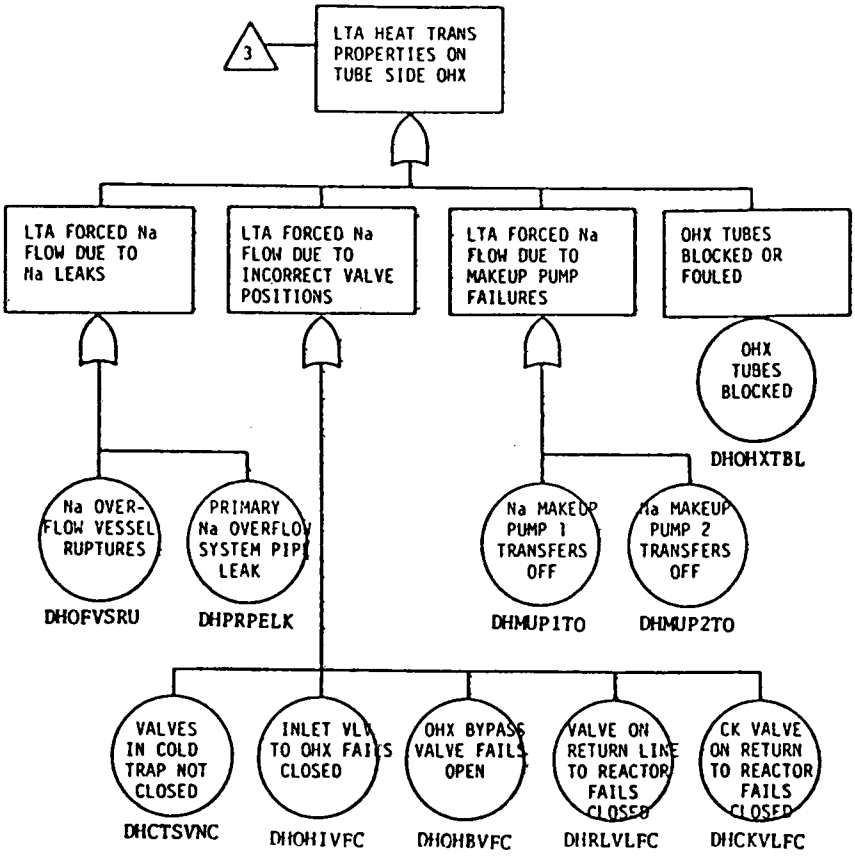


Figure A.1. (continued).

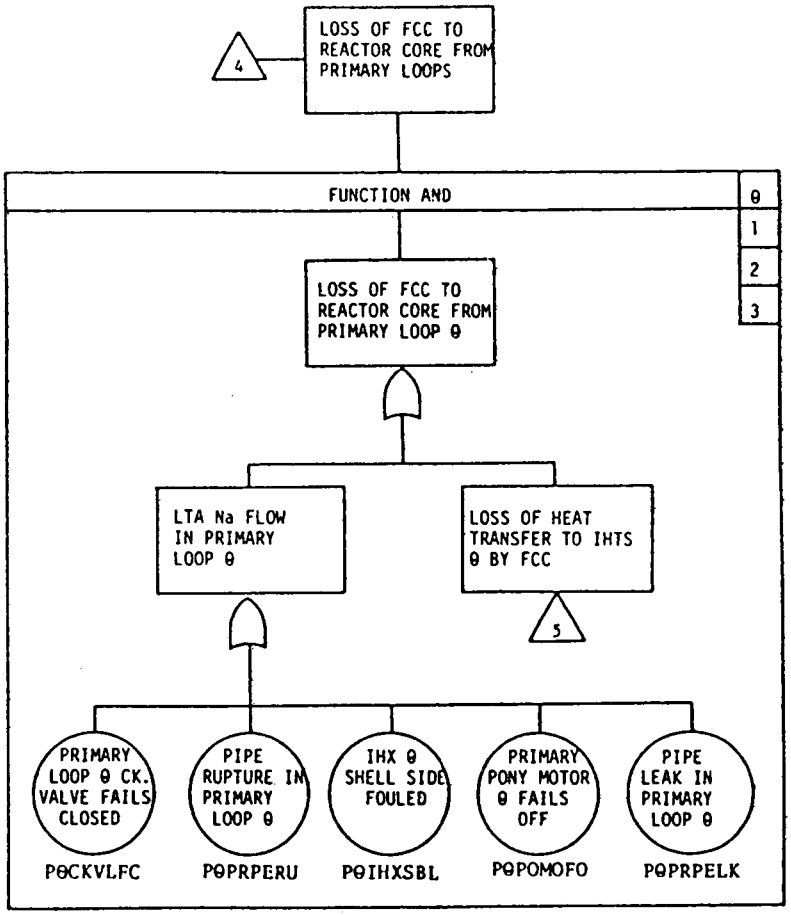


Figure A.1. (continued).

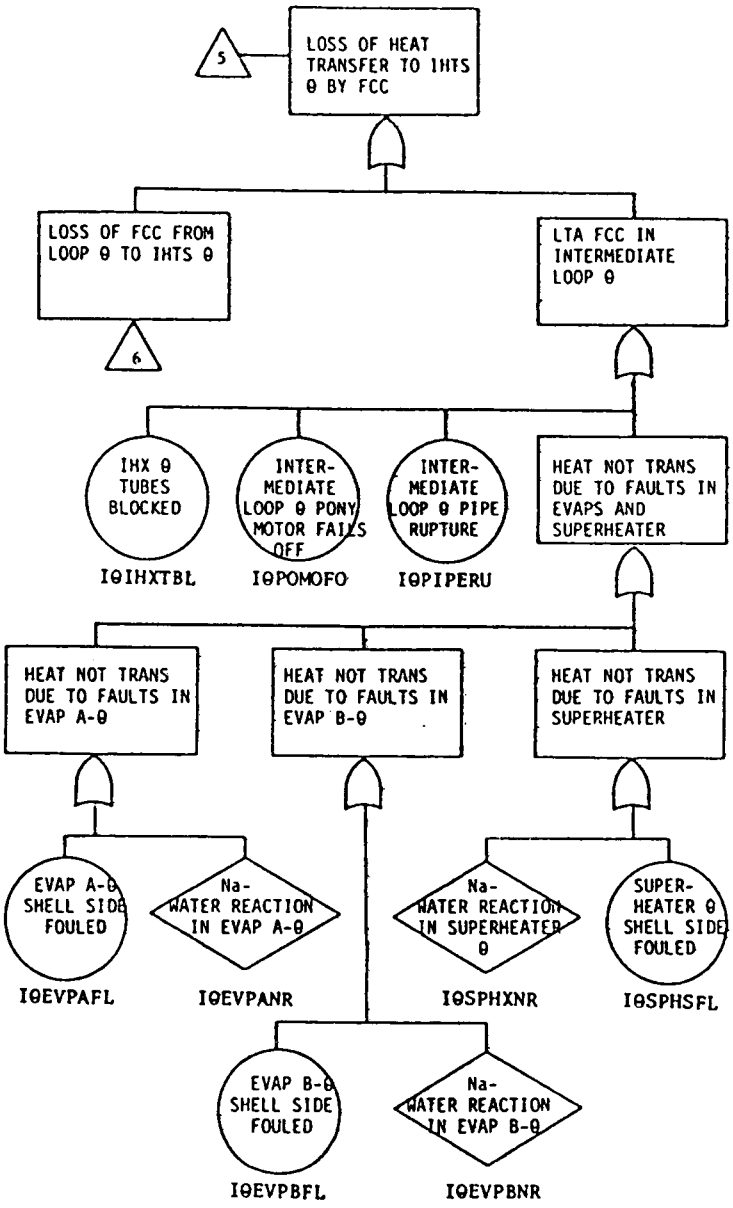


Figure A.1. (continued).

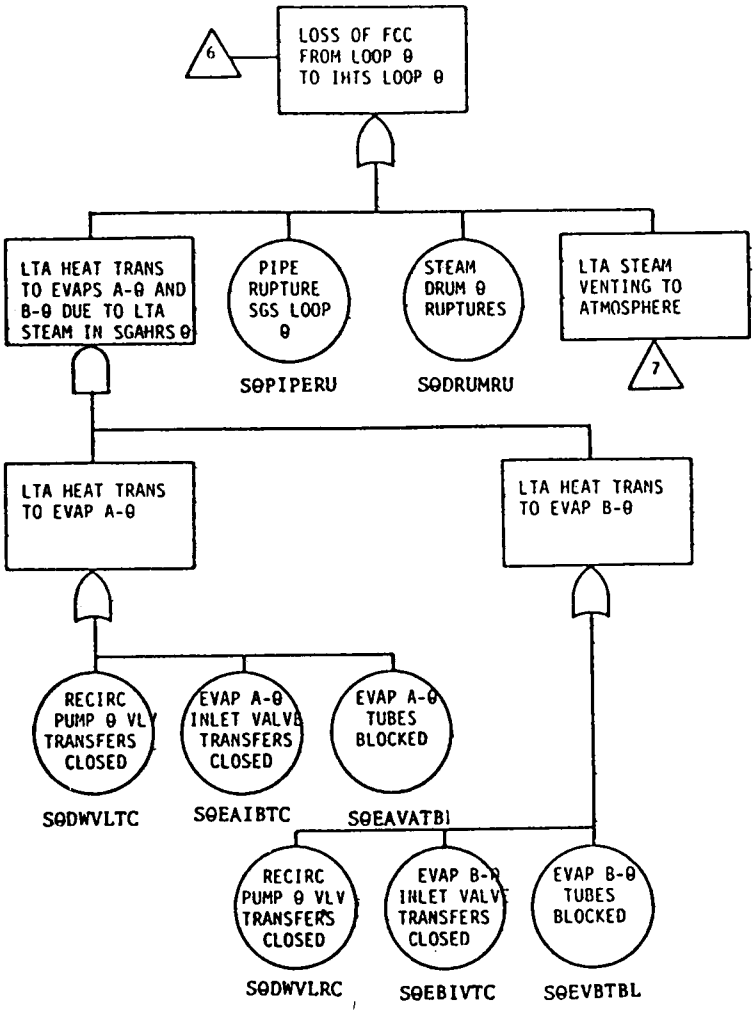


Figure A.1. (continued).

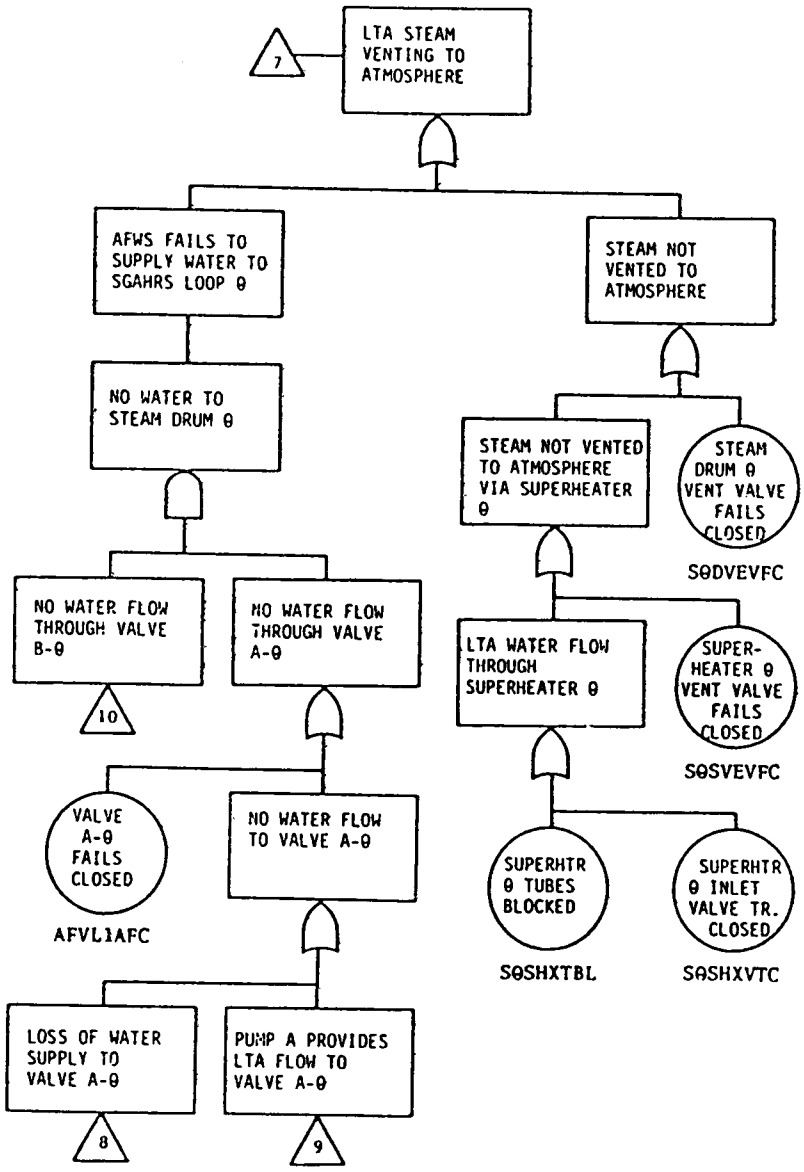


Figure A.1. (continued).

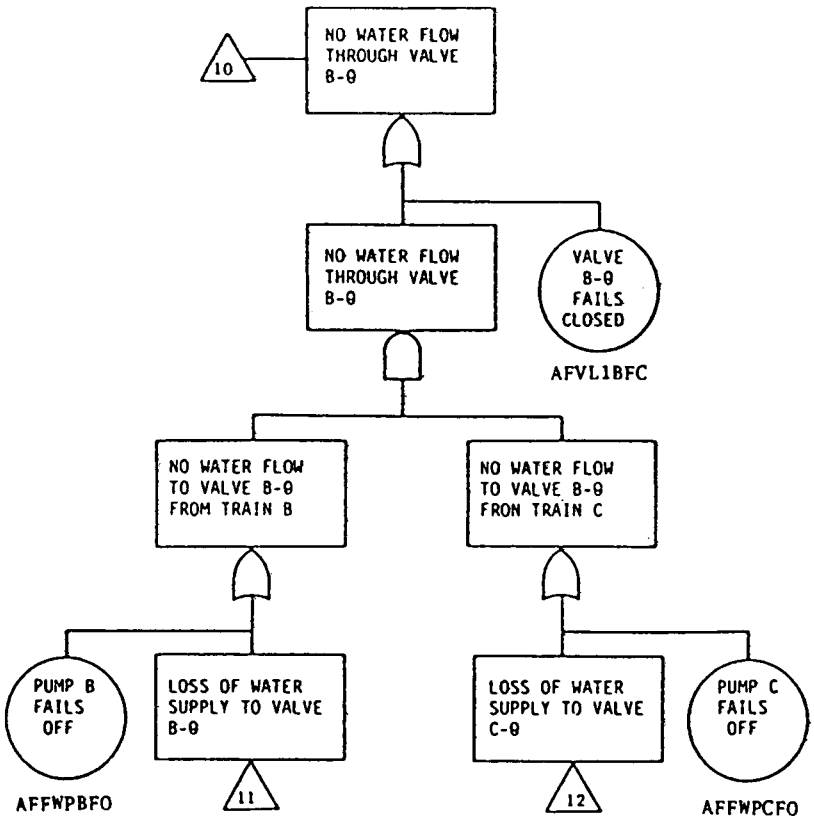


Figure A.1. (continued).

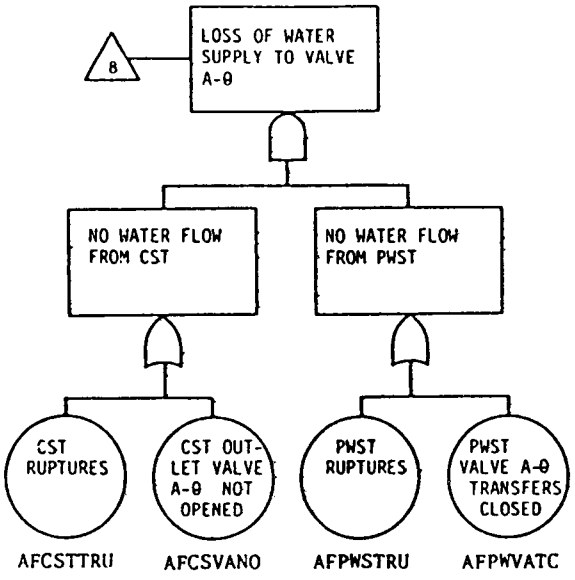


Figure A.1. (continued).

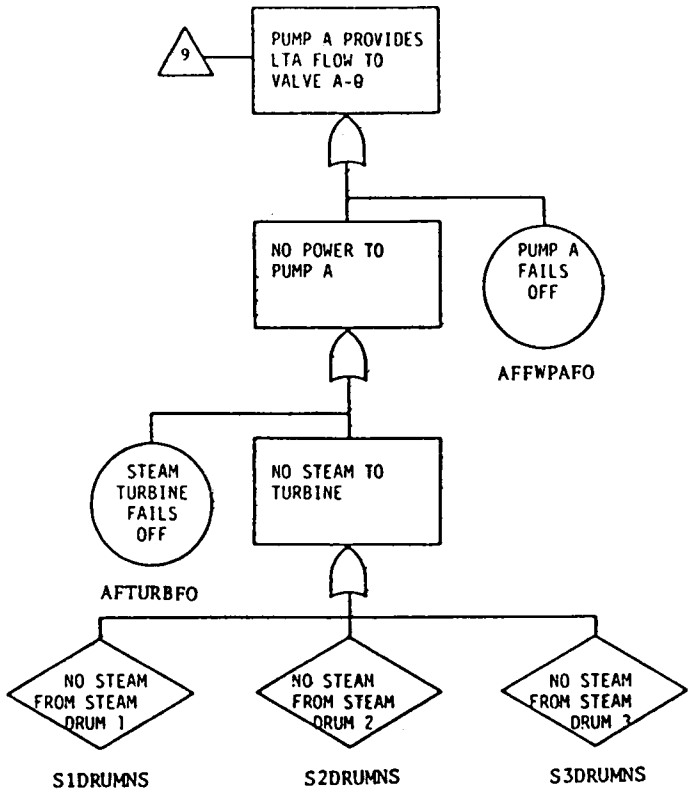


Figure A.1. (continued).

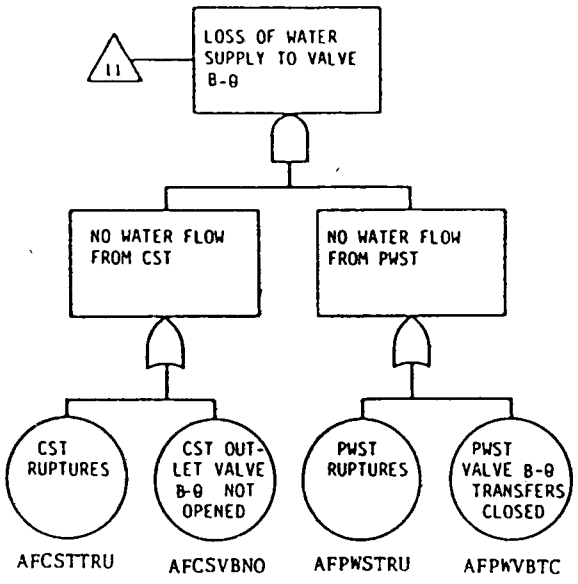


Figure A.1. (continued).

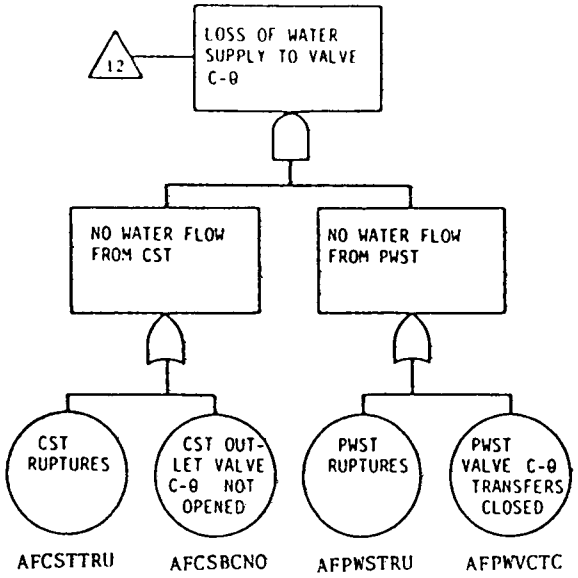


Figure A.1. (continued).

APPENDIX B

CRBRP SYSTEM INTERFACE TABLES

CRBRP SYSTEM INTERFACE TABLES

The CRBRP system interface tables aid in the development of the systems interaction fault tree. These tables identify all support systems to a particular front line system. These tables were obtained from the system design descriptions of the Clinch River Breeder Reactor Plant[4] and are presented in Tables B.1 through B.40.

Table B.1 CRBRP system interface table for the Power Transmission system (system 11)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
69	BALANCE OF PLANT INSTRUMENTATION & CONTROL SYSTEM
72	MAIN AND AUXILIARY STEAM SYSTEM
75B	TREATED WATER SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM

Table B.2 CRBRP system interface table for the Building Electrical Power System (system 12)

SYSTEM NUMBER	SYSTEM NAME
11	POWER TRANSMISSION SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
75A	PLANT SERVICE WATER SYSTEM
75B	TREATED WATER SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM

Table B.3 CRBRP system interface table for the Compressed Gas System (system 22)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
75B	TREATED WATER SYSTEM
76	WASTE WATER TREATMENT SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.4 CRBRP system interface table for the Chilled Water System (system 23)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
75A	PLANT SERVICE WATER SYSTEM
75B	TREATED WATER SYSTEM
76	WASTE WATER TREATMENT SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
90	PLANT CONTROL SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.5 CRBRP system interface table for the Radioactive Waste System (system 24)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
75A	PLANT SERVICE WATER SYSTEM
75B	TREATED WATER SYSTEM
76	WASTE WATER TREATMENT SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
90	PLANT CONTROL SYSTEM

Table B.6 CRBRP system interface table for the Nuclear Island HVAC System (system 25A)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
23	CHILLED WATER SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
75A	PLANT SERVICE WATER SYSTEM
75B	TREATED WATER SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
96	RADIATION MONITORING SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.7 CRBRP system interface table for the Balance of Plant HVAC System (system 25B)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
23	CHILLED WATER SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
75A	PLANT SERVICE WATER SYSTEM
75B	TREATED WATER SYSTEM
76	WASTE WATER TREATMENT SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.8 CRBRP system interface table for the Sodium Fire Protection System (system 26A)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
27	REACTOR CONTAINMENT SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
90	PLANT CONTROL SYSTEM

Table B.9 CRBRP system interface table for the Non-Sodium Fire Protection System (system 26B)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
27	REACTOR CONTAINMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
75A	PLANT SERVICE WATER SYSTEM
75B	TREATED WATER SYSTEM
76	WASTE WATER TREATMENT SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM

Table B.10 CRBRP system interface table for the Reactor Containment System (system 27)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
23	CHILLED WATER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26A	SODIUM FIRE PROTECTION SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
31	REACTOR SYSTEM
32	REACTOR ENCLOSURE SYSTEM
41	REACTOR REFUELING SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
51A	PRIMARY HEAT TRANSPORT SYSTEM
51B	INTERMEDIATE HEAT TRANSPORT SYSTEM
56	REACTOR HEAT TRANSPORT INSTRUMENTATION SYSTEM
66	LIQUID METAL TO GAS LEAK DETECTION SYSTEM
68	PIPING & EQUIP. ELECTRICAL HTNG AND CONTROL SYSTEM
81	AUXILIARY LIQUID METAL SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
85	IMPURITY MONITORING AND ANALYSIS SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
92	REACTOR AND VESSEL INSTRUMENTATION SYSTEM
94	FUEL FAILURE MONITORING SYSTEM
96	RADIATION MONITORING SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.11 CRBRP system interface table for the Recirculating Gas Cooling System (system 28)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
23	CHILLED WATER SYSTEM
24	RADIOACTIVE WASTE SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
66	LIQUID METAL TO GAS LEAK DETECTION SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.12 CRBRP system interface table for the Reactor System (system 31)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
24	RADIOACTIVE WASTE SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
32	REACTOR ENCLOSURE SYSTEM
41	REACTOR REFUELING SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
51A	PRIMARY HEAT TRANSPORT SYSTEM
56	REACTOR HEAT TRANSPORT INSTRUMENTATION SYSTEM
81	AUXILIARY LIQUID METAL SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
85	IMPURITY MONITORING AND ANALYSIS SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
92	REACTOR AND VESSEL INSTRUMENTATION SYSTEM
94	FUEL FAILURE MONITORING SYSTEM
95	FLUX MONITORING SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.13 CRBRP system interface table for the Reactor Enclosure System (system 32)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
24	RADIOACTIVE WASTE SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26A	SODIUM FIRE PROTECTION SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
31	REACTOR SYSTEM
41	REACTOR REFUELING SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
51A	PRIMARY HEAT TRANSPORT SYSTEM
66	LIQUID METAL TO GAS LEAK DETECTION SYSTEM
68	PIPING & EQUIP. ELECTRICAL HTNG AND CONTROL SYSTEM
81	AUXILIARY LIQUID METAL SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
92	REACTOR AND VESSEL INSTRUMENTATION SYSTEM
95	FLUX MONITORING SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.14 CRBRP system interface table for the Reactor Refueling System (system 41)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
23	CHILLED WATER SYSTEM
24	RADIOACTIVE WASTE SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26A	SODIUM FIRE PROTECTION SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
31	REACTOR SYSTEM
32	REACTOR ENCLOSURE SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
66	LIQUID METAL TO GAS LEAK DETECTION SYSTEM
68	PIPING & EQUIP. ELECTRICAL HTNG AND CONTROL SYSTEM
81	AUXILIARY LIQUID METAL SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
85	IMPURITY MONITORING AND ANALYSIS SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
95	FLUX MONITORING SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.15 CRBRP system interface table for the Nuclear Island Maintenance Equipment System (system 44)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
23	CHILLED WATER SYSTEM
24	RADIOACTIVE WASTE SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26A	SODIUM FIRE PROTECTION SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
31	REACTOR SYSTEM
32	REACTOR ENCLOSURE SYSTEM
41	REACTOR REFUELING SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
51A	PRIMARY HEAT TRANSPORT SYSTEM
51B	INTERMEDIATE HEAT TRANSPORT SYSTEM
52	STEAM GENERATOR AUXILIARY HEAT REMOVAL SYSTEM
53	STEAM GENERATOR SYSTEM
72	MAIN AND AUXILIARY STEAM SYSTEM
75B	TREATED WATER SYSTEM
76	WASTE WATER TREATMENT SYSTEM
81	AUXILIARY LIQUID METAL SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
90	PLANT CONTROL SYSTEM
96	RADIATION MONITORING SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.16 CRBRP system interface table for the Balance of Plant Maintenance System (system 45)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
24	RADIOACTIVE WASTE SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26A	SODIUM FIRE PROTECTION SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
75B	TREATED WATER SYSTEM
76	WASTE WATER TREATMENT SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.17 CRBRP system interface table for the Primary Heat Transport System (system 51A)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26A	SODIUM FIRE PROTECTION SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
31	REACTOR SYSTEM
32	REACTOR ENCLOSURE SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
51B	INTERMEDIATE HEAT TRANSPORT SYSTEM
56	REACTOR HEAT TRANSPORT INSTRUMENTATION SYSTEM
66	LIQUID METAL TO GAS LEAK DETECTION SYSTEM
68	PIPING & EQUIP. ELECTRICAL HTNG AND CONTROL SYSTEM
81	AUXILIARY LIQUID METAL SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
85	IMPURITY MONITORING AND ANALYSIS SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
92	REACTOR AND VESSEL INSTRUMENTATION SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.18 CRBRP system interface table for the Intermediate Heat Transport System (system 51B)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26A	SODIUM FIRE PROTECTION SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
51A	PRIMARY HEAT TRANSPORT SYSTEM
52	STEAM GENERATOR AUXILIARY HEAT REMOVAL SYSTEM
53	STEAM GENERATOR SYSTEM
56	REACTOR HEAT TRANSPORT INSTRUMENTATION SYSTEM
66	LIQUID METAL TO GAS LEAK DETECTION SYSTEM
68	PIPING & EQUIP. ELECTRICAL HTNG AND CONTROL SYSTEM
81	AUXILIARY LIQUID METAL SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
85	IMPURITY MONITORING AND ANALYSIS SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
96	RADIATION MONITORING SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.19 CRBRP system interface table for the Steam Generator Auxiliary Heat Removal System (system 52)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
23	CHILLED WATER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
53	STEAM GENERATOR SYSTEM
56	REACTOR HEAT TRANSPORT INSTRUMENTATION SYSTEM
69	BALANCE OF PLANT INSTRUMENTATION & CONTROL SYSTEM
71	FEEDWATER AND CONDENSATE SYSTEM
75B	TREATED WATER SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM

Table B.20 CRBRP system interface table for the Steam Generator System (system 53)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
24	RADIOACTIVE WASTE SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
51B	INTERMEDIATE HEAT TRANSPORT SYSTEM
52	STEAM GENERATOR AUXILIARY HEAT REMOVAL SYSTEM
56	REACTOR HEAT TRANSPORT INSTRUMENTATION SYSTEM
68	PIPING & EQUIP. ELECTRICAL HTNG AND CONTROL SYSTEM
69	BALANCE OF PLANT INSTRUMENTATION & CONTROL SYSTEM
71	FEEDWATER AND CONDENSATE SYSTEM
72	MAIN AND AUXILIARY STEAM SYSTEM
75A	PLANT SERVICE WATER SYSTEM
81	AUXILIARY LIQUID METAL SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.21 CRBRP system interface table for the Reactor Heat Transport Instrumentation System (system 56)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
51A	PRIMARY HEAT TRANSPORT SYSTEM
53	STEAM GENERATOR SYSTEM
69	BALANCE OF PLANT INSTRUMENTATION & CONTROL SYSTEM
75A	PLANT SERVICE WATER SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.22 CRBRP system interface table for the Liquid Metal to Gas Leak Detection System (system 66)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.23 CRBRP system interface table for the Piping and Equipment Electrical Heating and Control System (system 68)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
90	PLANT CONTROL SYSTEM

Table B.24 CRBRP system interface table for the Balance of Plant Instrumentation and Control System (system 69)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
23	CHILLED WATER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
56	REACTOR HEAT TRANSPORT INSTRUMENTATION SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.25 CRBRP system interface table for the Feedwater and Condensate System (system 71)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
69	BALANCE OF PLANT INSTRUMENTATION & CONTROL SYSTEM
72	MAIN AND AUXILIARY STEAM SYSTEM
73	HEAT REJECTION SYSTEM
75B	TREATED WATER SYSTEM
76	WASTE WATER TREATMENT SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.26 CRBRP system interface table for the Main and Auxiliary Steam System (system 72)

SYSTEM NUMBER	SYSTEM NAME
11	POWER TRANSMISSION SYSTEM
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
69	BALANCE OF PLANT INSTRUMENTATION & CONTROL SYSTEM
71	FEEDWATER AND CONDENSATE SYSTEM
73	HEAT REJECTION SYSTEM
75A	PLANT SERVICE WATER SYSTEM
75B	TREATED WATER SYSTEM
76	WASTE WATER TREATMENT SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.27 CRBRP system interface table for the Heat Rejection System (system 73)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
69	BALANCE OF PLANT INSTRUMENTATION & CONTROL SYSTEM
71	FEEDWATER AND CONDENSATE SYSTEM
74	RIVER WATER SERVICE SYSTEM
75A	PLANT SERVICE WATER SYSTEM
75B	TREATED WATER SYSTEM
76	WASTE WATER TREATMENT SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.28 CRBRP system interface table for the River Water Service System (system 74)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
69	BALANCE OF PLANT INSTRUMENTATION & CONTROL SYSTEM
75B	TREATED WATER SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM

Table B.29 CRBRP system interface table for the Plant Service Water System (system 75A)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PPOTECTION SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
53	STEAM GENERATOR SYSTEM
69	BALANCE OF PLANT INSTRUMENTATION & CONTROL SYSTEM
72	MAIN AND AUXILIARY STEAM SYSTEM
73	HEAT REJECTION SYSTEM
75B	TREATED WATER SYSTEM
76	WASTE WATER TREATMENT SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM

Table B.30 CRBRP system interface table for the Waste Water Treatment System (system 76)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
69	BALANCE OF PLANT INSTRUMENTATION & CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.31 CRBRP system interface table for the Auxiliary Liquid Metal System (system 81)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
23	CHILLED WATER SYSTEM
24	RADIOACTIVE WASTE SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26A	SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
66	LIQUID METAL TO GAS LEAK DETECTION SYSTEM
68	PIPING & EQUIP. ELECTRICAL HTNG AND CONTROL SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
85	IMPURITY MONITORING AND ANALYSIS SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM

Table B.32 CRBRP system interface table for the Inert Gas Receiving and Processing System (system 82)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
23	CHILLED WATER SYSTEM
24	RADIOACTIVE WASTE SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
56	REACTOR HEAT TRANSPORT INSTRUMENTATION SYSTEM
68	PIPING & EQUIP. ELECTRICAL HTNG AND CONTROL SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.33 CRBRP system interface table for the Impurity Monitoring and Analysis System (system 85)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
24	RADIOACTIVE WASTE SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
66	LIQUID METAL TO GAS LEAK DETECTION SYSTEM
68	PIPING & EQUIP. ELECTRICAL HTNG AND CONTROL SYSTEM
81	AUXILIARY LIQUID METAL SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
90	PLANT CONTROL SYSTEM
94	FUEL FAILURE MONITORING SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.34 CRBRP system interface table for the Plant Control System (system 90)

SYSTEM NUMBER	SYSTEM NAME
11	POWER TRANSMISSION SYSTEM
12	BUILDING ELECTRICAL POWER SYSTEM
23	CHILLED WATER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26A	SODIUM FIRE PROTECTION SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
31	REACTOR SYSTEM
32	REACTOR ENCLOSURE SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
56	REACTOR HEAT TRANSPORT INSTRUMENTATION SYSTEM
66	LIQUID METAL TO GAS LEAK DETECTION SYSTEM
69	BALANCE OF PLANT INSTRUMENTATION & CONTROL SYSTEM
81	AUXILIARY LIQUID METAL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
92	REACTOR AND VESSEL INSTRUMENTATION SYSTEM
94	FUEL FAILURE MONITORING SYSTEM
95	FLUX MONITORING SYSTEM
96	RADIATION MONITORING SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.35 CRBRP system interface table for the Plant Data Handling and Display System (system 91)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
32	REACTOR ENCLOSURE SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM

Table B.36 CRBRP system interface table for the Reactor and Vessel Instrumentation System (system 92)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
27	REACTOR CONTAINMENT SYSTEM
31	REACTOR SYSTEM
32	REACTOR ENCLOSURE SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
56	REACTOR HEAT TRANSPORT INSTRUMENTATION SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM

Table B.37 CRBRP system interface table for the Fuel Failure Monitoring System (system 94)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
32	REACTOR ENCLOSURE SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
51A	PRIMARY HEAT TRANSPORT SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
85	IMPURITY MONITORING AND ANALYSIS SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
96	RADIATION MONITORING SYSTEM

Table B.38 CRBRP system interface table for the Flux Monitoring System (system 95)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
31	REACTOR SYSTEM
32	REACTOR ENCLOSURE SYSTEM
41	REACTOR REFUELING SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.39 CRBRP system interface table for the Radiation Monitoring System (system 96)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
23	CHILLED WATER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
25B	BALANCE OF PLANT HVAC SYSTEM
26B	NON-SODIUM FIRE PROTECTION SYSTEM
27	REACTOR CONTAINMENT SYSTEM
28	RECIRCULATING GAS COOLING SYSTEM
32	REACTOR ENCLOSURE SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
99	PLANT PROTECTION SYSTEM

Table B.40 CRBRP system interface table for the Plant Protection System (system 99)

SYSTEM NUMBER	SYSTEM NAME
12	BUILDING ELECTRICAL POWER SYSTEM
22	COMPRESSED GAS SYSTEM
23	CHILLED WATER SYSTEM
25A	NUCLEAR ISLAND HVAC SYSTEM
27	REACTOR CONTAINMENT SYSTEM
31	REACTOR SYSTEM
32	REACTOR ENCLOSURE SYSTEM
44	NUCLEAR ISLAND MAINTENANCE EQUIPMENT SYSTEM
45	BALANCE OF PLANT MAINTENANCE SYSTEM
56	REACTOR HEAT TRANSPORT INSTRUMENTATION SYSTEM
82	INERT GAS RECEIVING AND PROCESSING SYSTEM
90	PLANT CONTROL SYSTEM
91	PLANT DATA HANDLING AND DISPLAY SYSTEM
92	REACTOR AND VESSEL INSTRUMENTATION SYSTEM
95	FLUX MONITORING SYSTEM
96	RADIATION MONITORING SYSTEM

APPENDIX C

CRBRP SHUTDOWN HEAT REMOVAL SYSTEM SYSTEMS INTERACTION FAULT TREE AT THE PRIMARY INTERFACE LEVEL

CRBRP SHUTDOWN HEAT REMOVAL SYSTEM SYSTEMS INTERACTION FAULT TREE AT THE PRIMARY INTERFACE LEVEL

The CRBRP SHRS logic models were developed in the fault tree format. A fault tree is a graphical representation of the failure logic of a system to a particular TOP event.

The logic model for the CRBRP SHRS at the primary interface level is presented in Figure C.1.

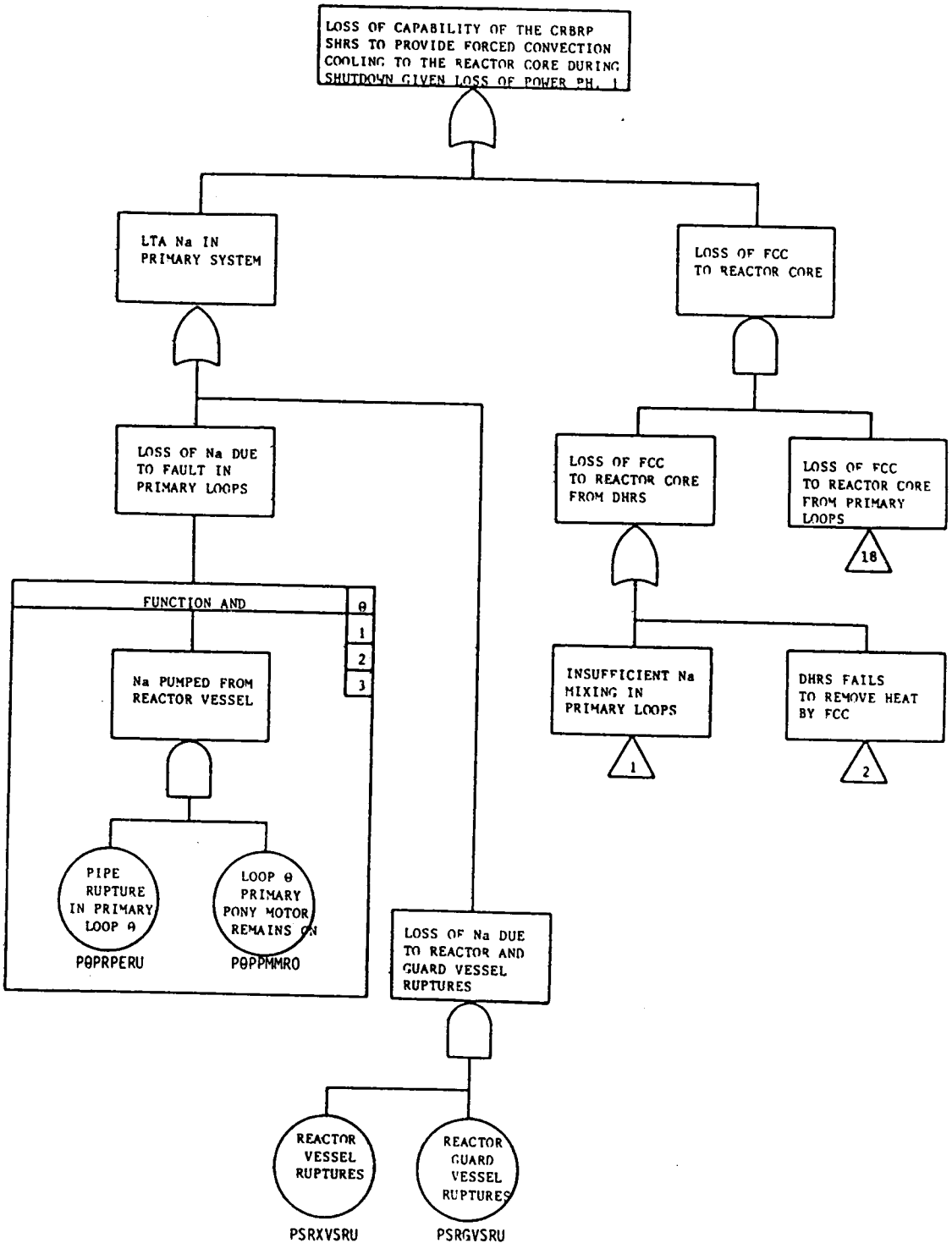
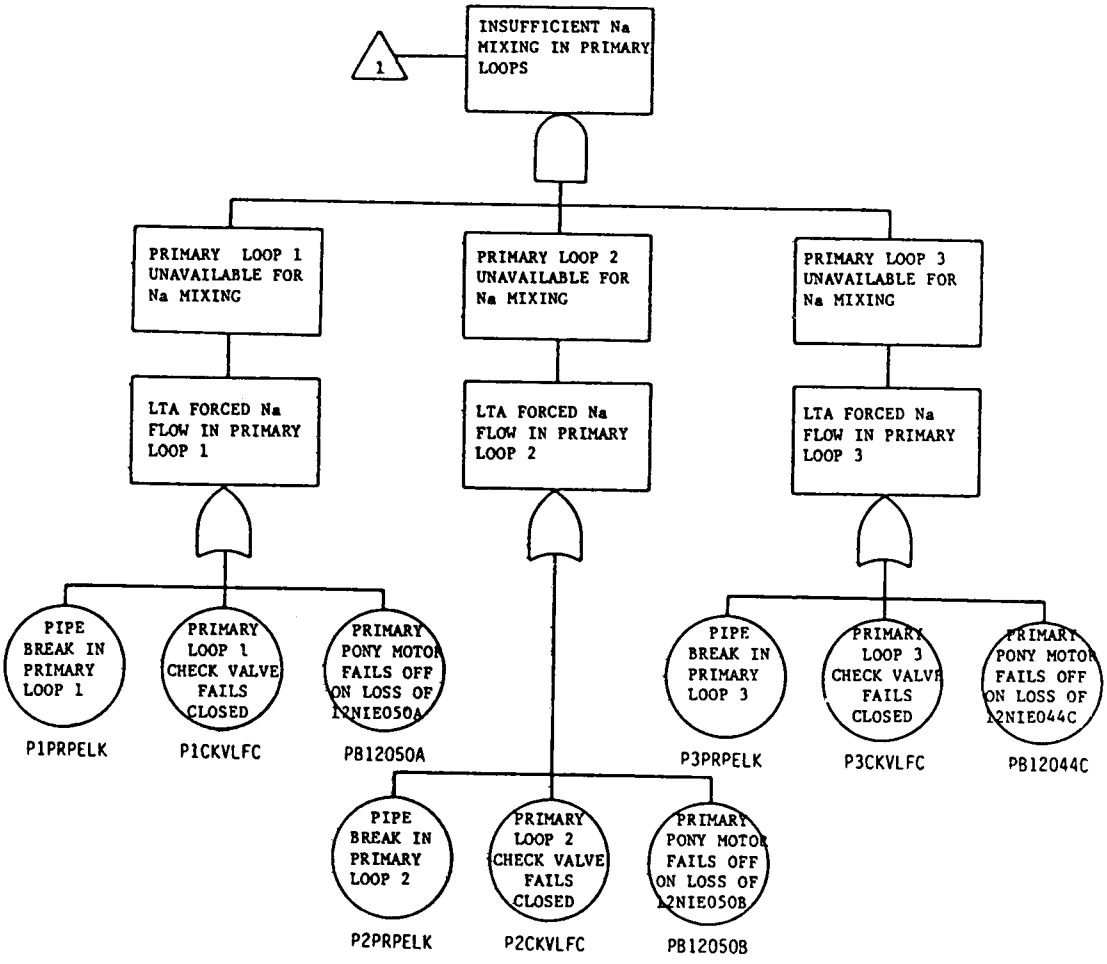


Figure C.1. CRBRP Shutdown Heat Removal System systems interaction fault tree at the primary interface level.



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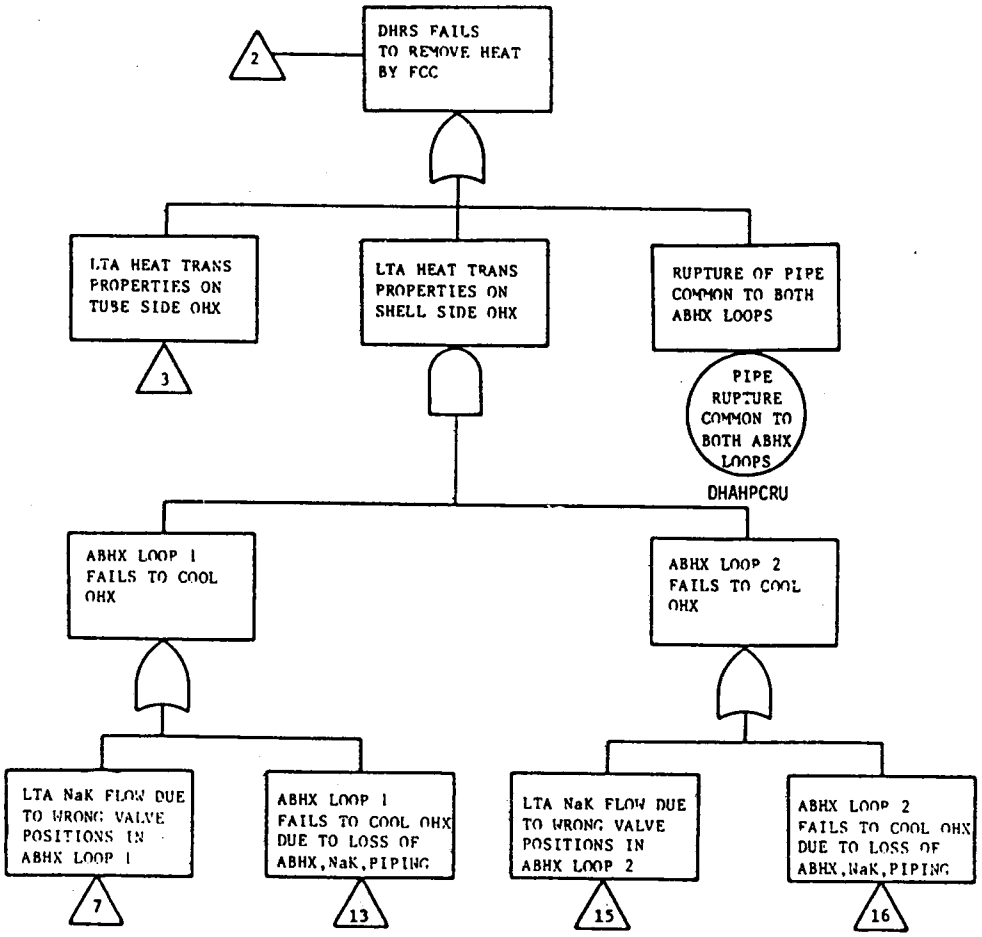

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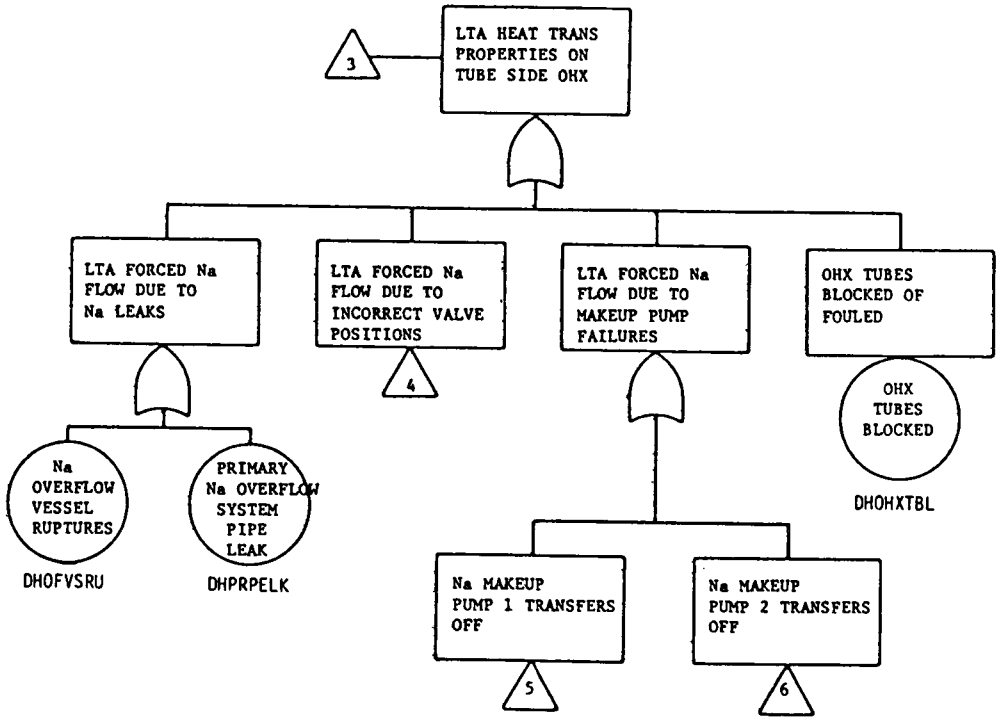

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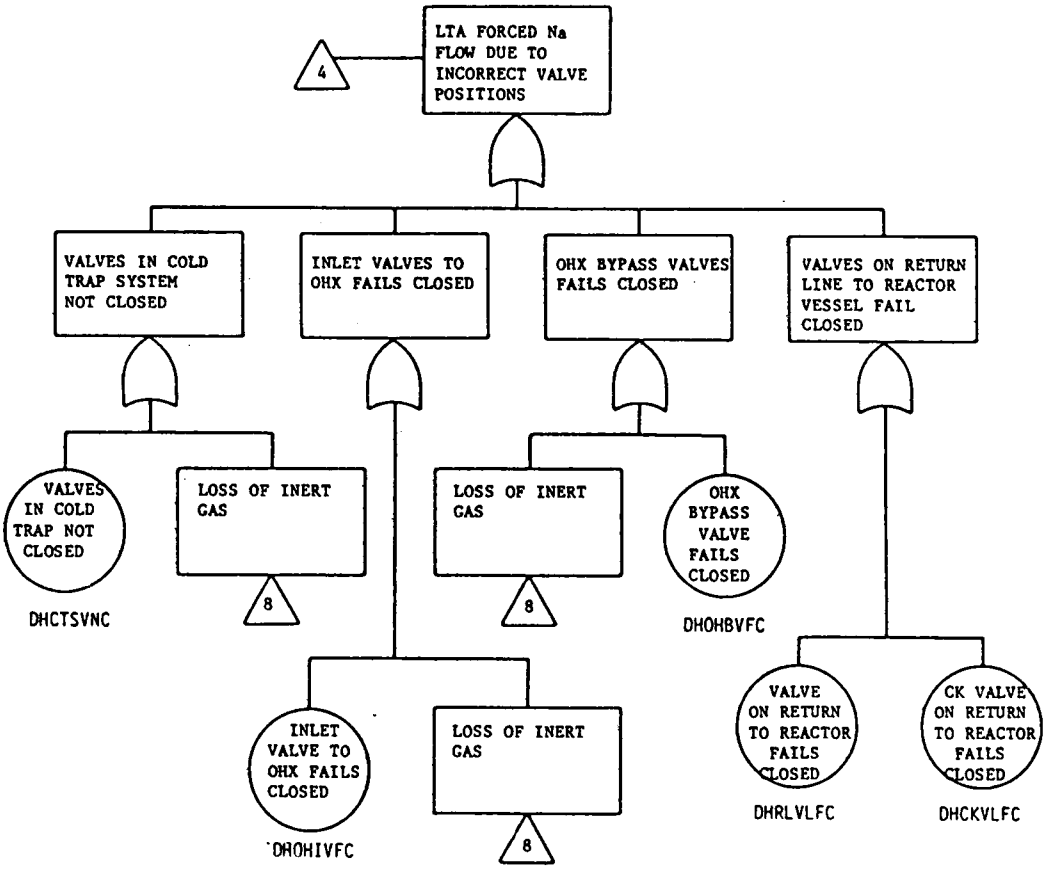

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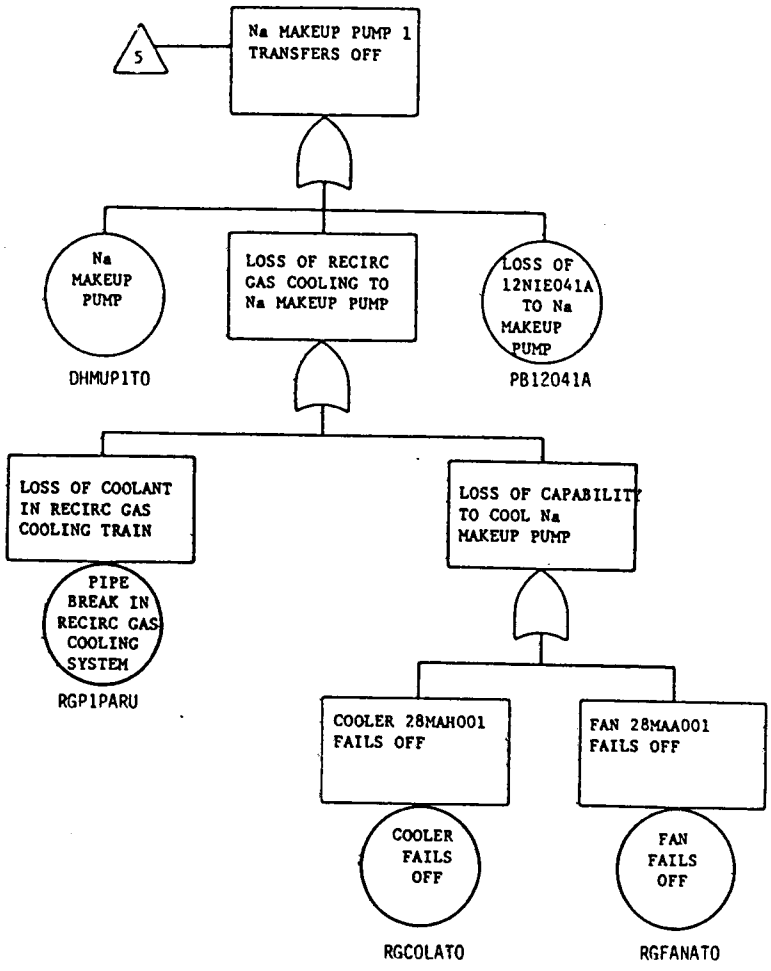

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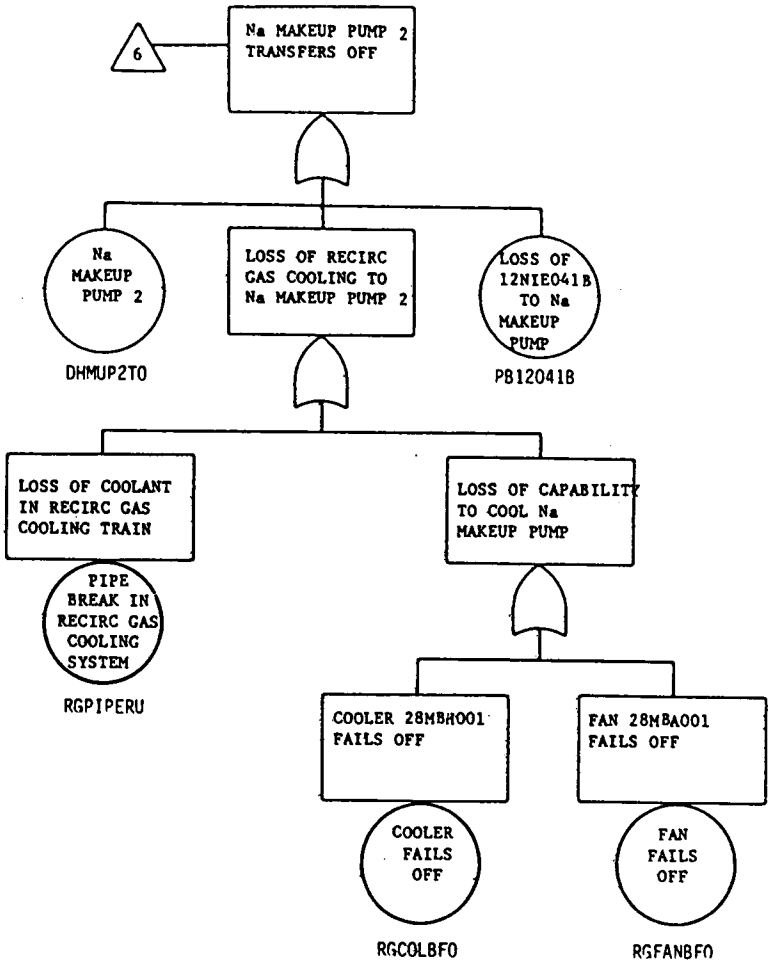

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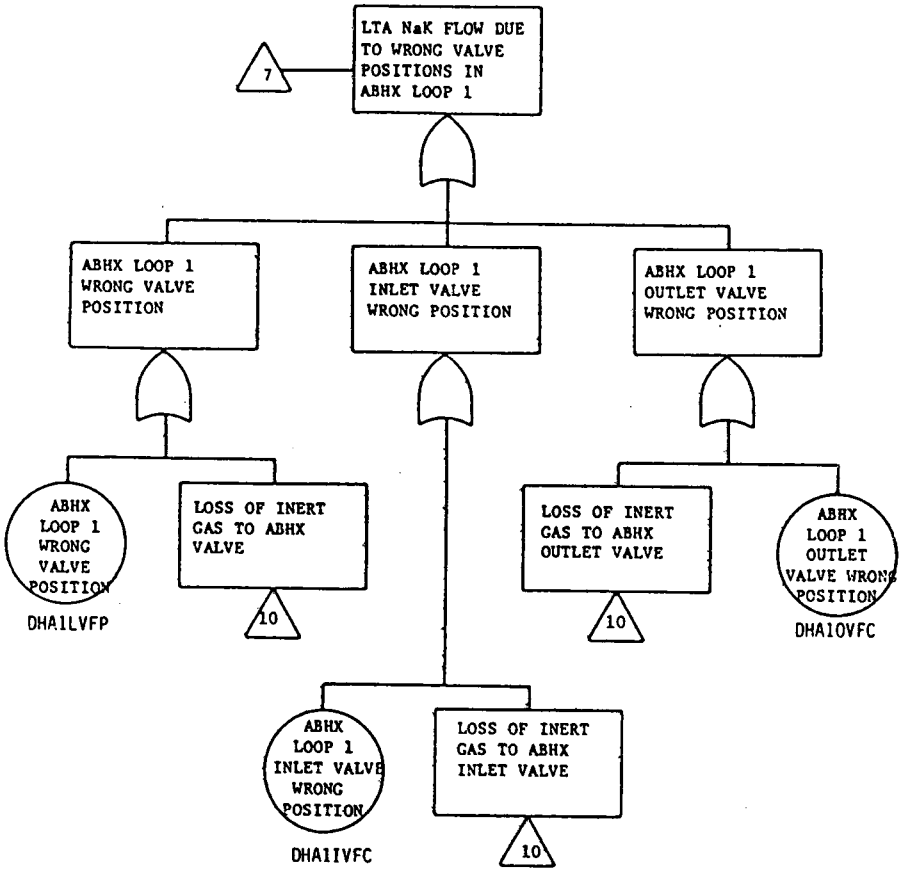

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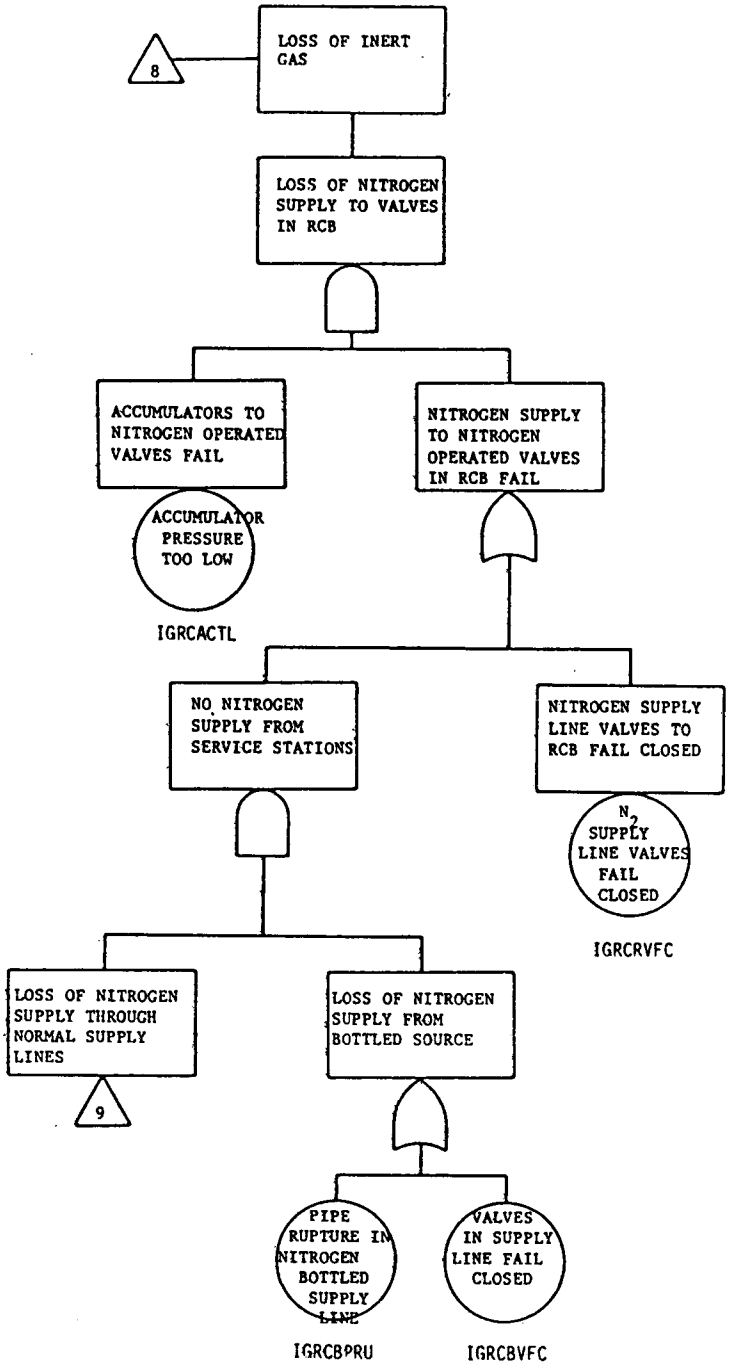

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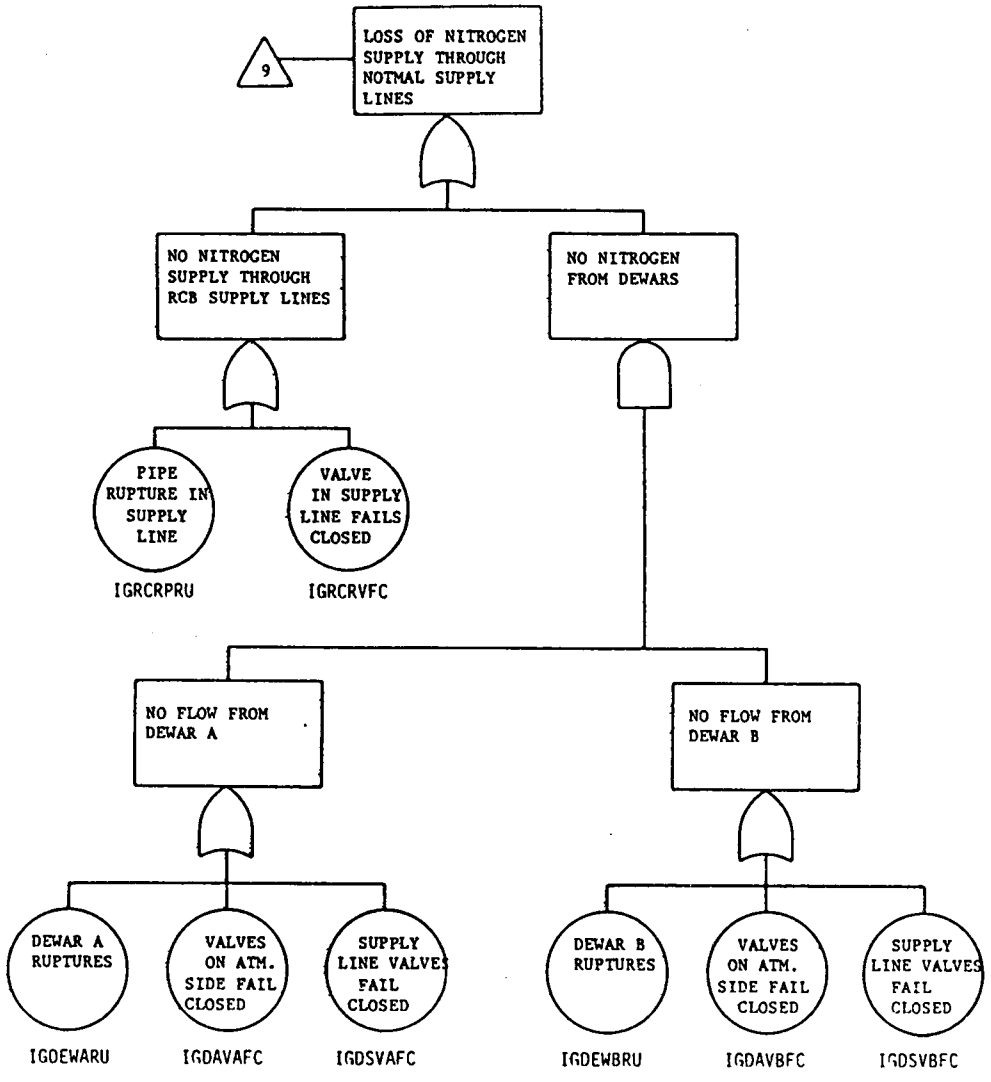

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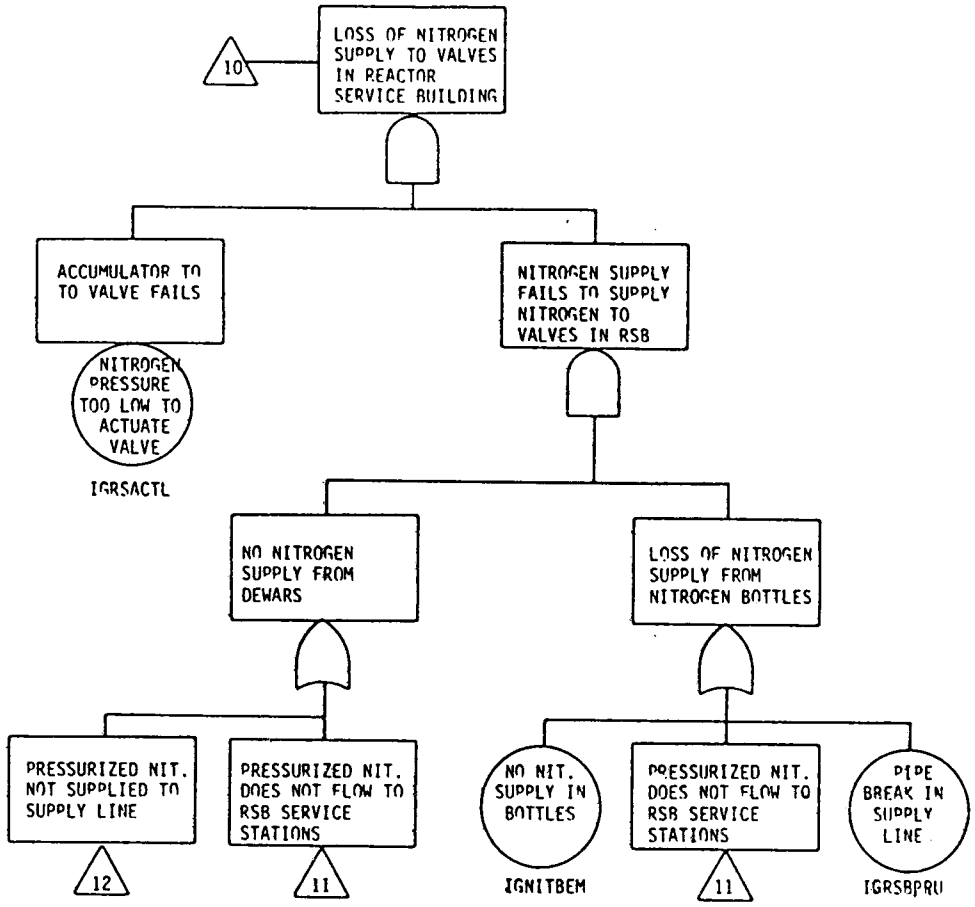

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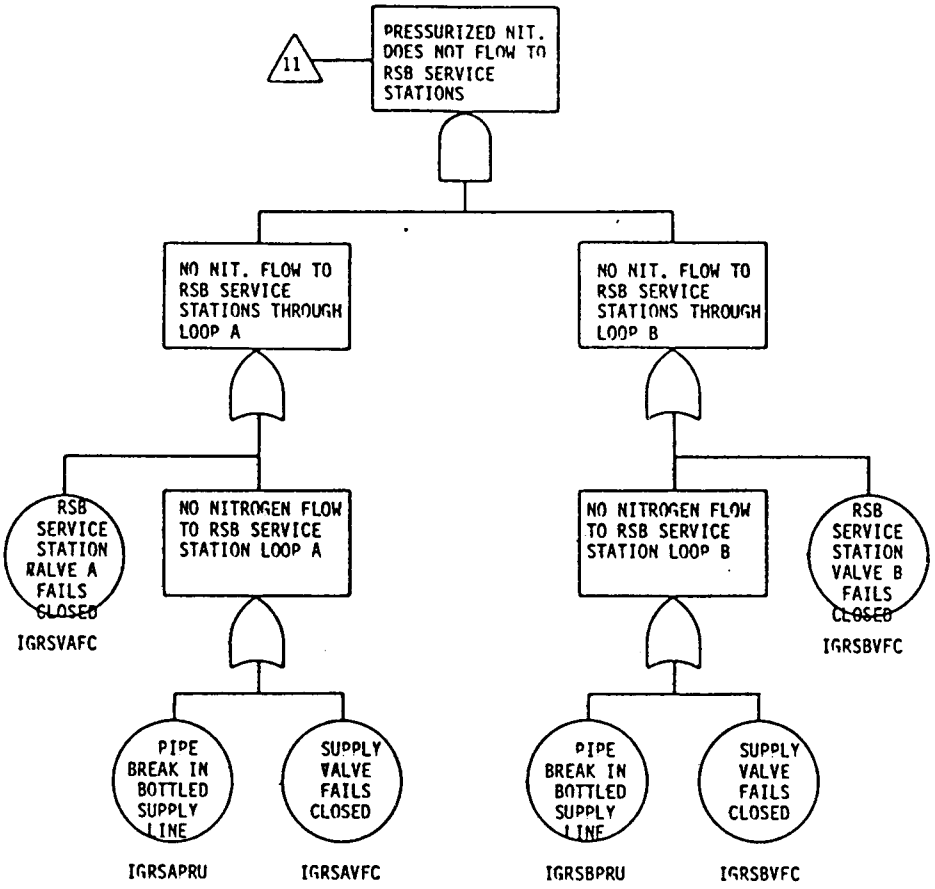

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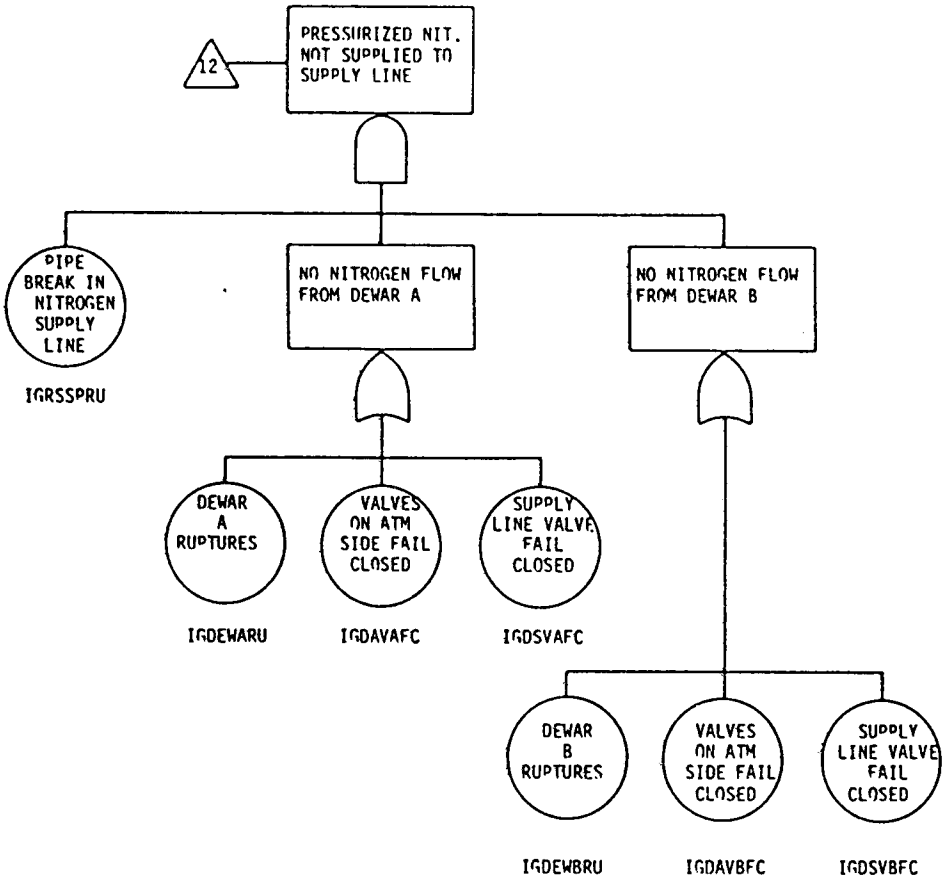

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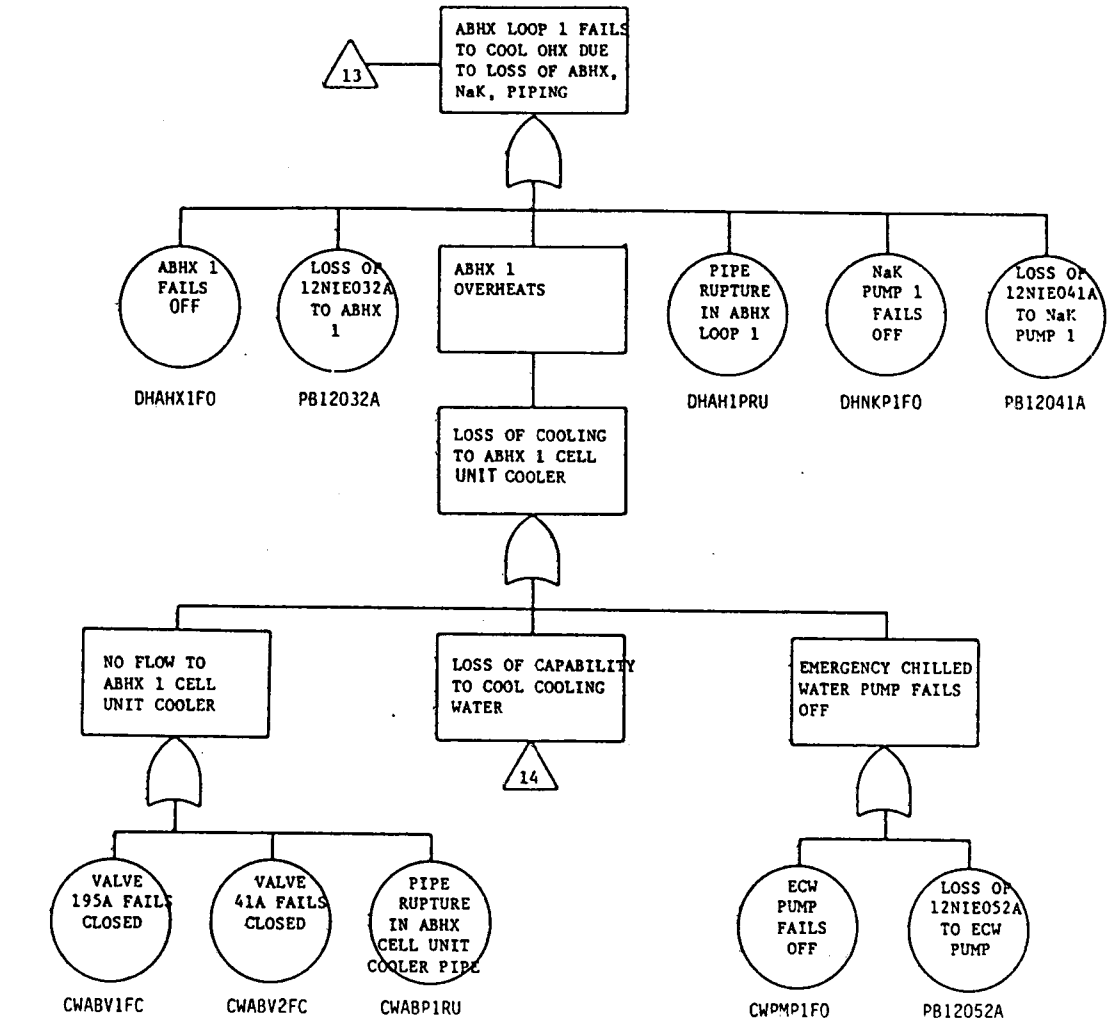

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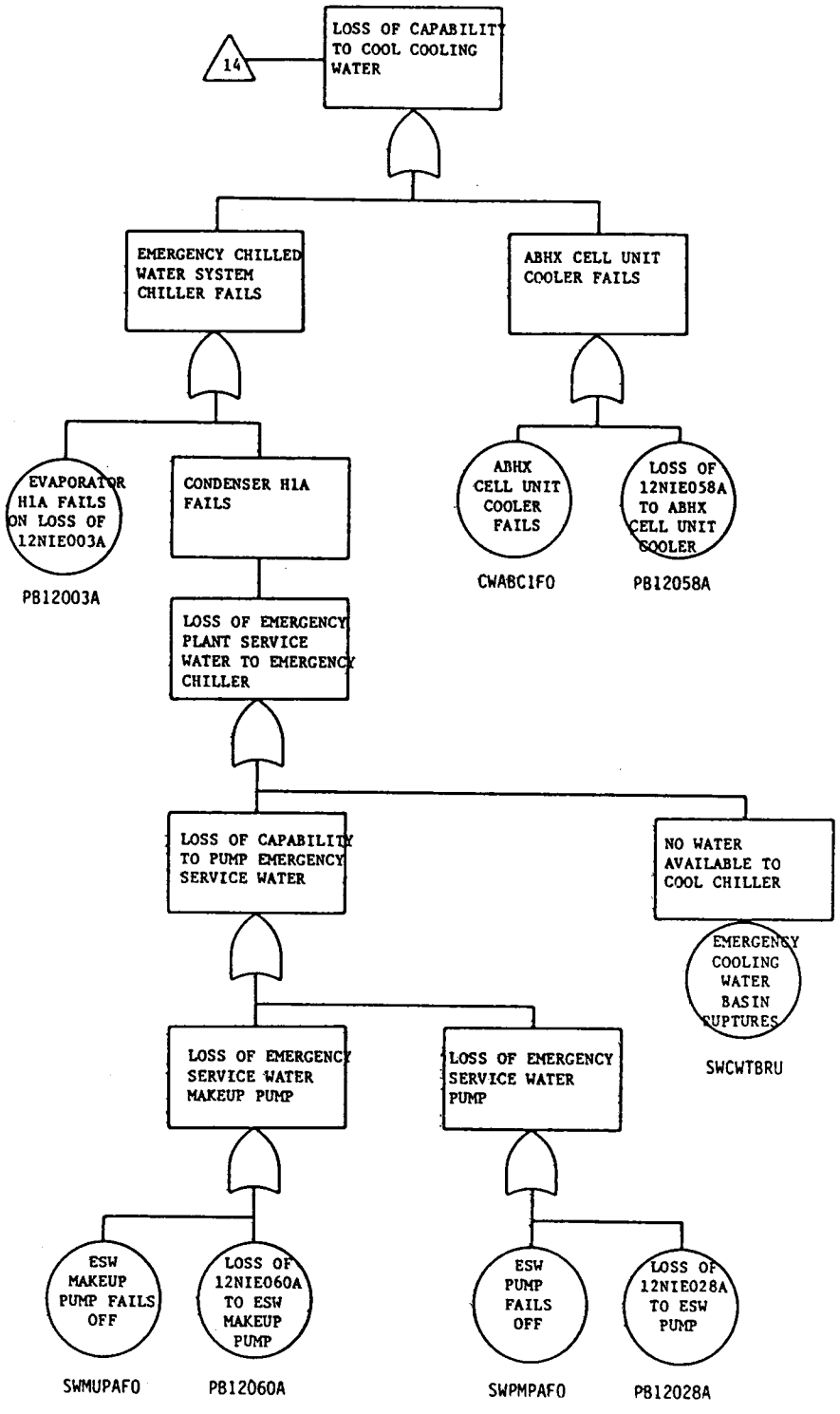

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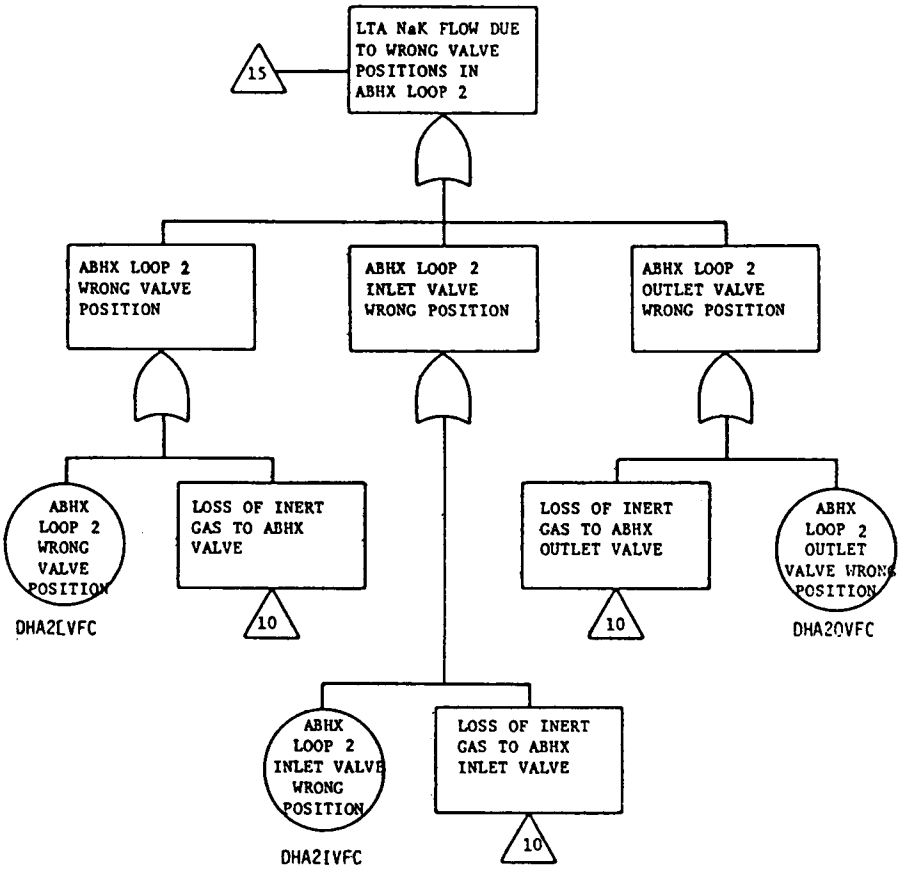

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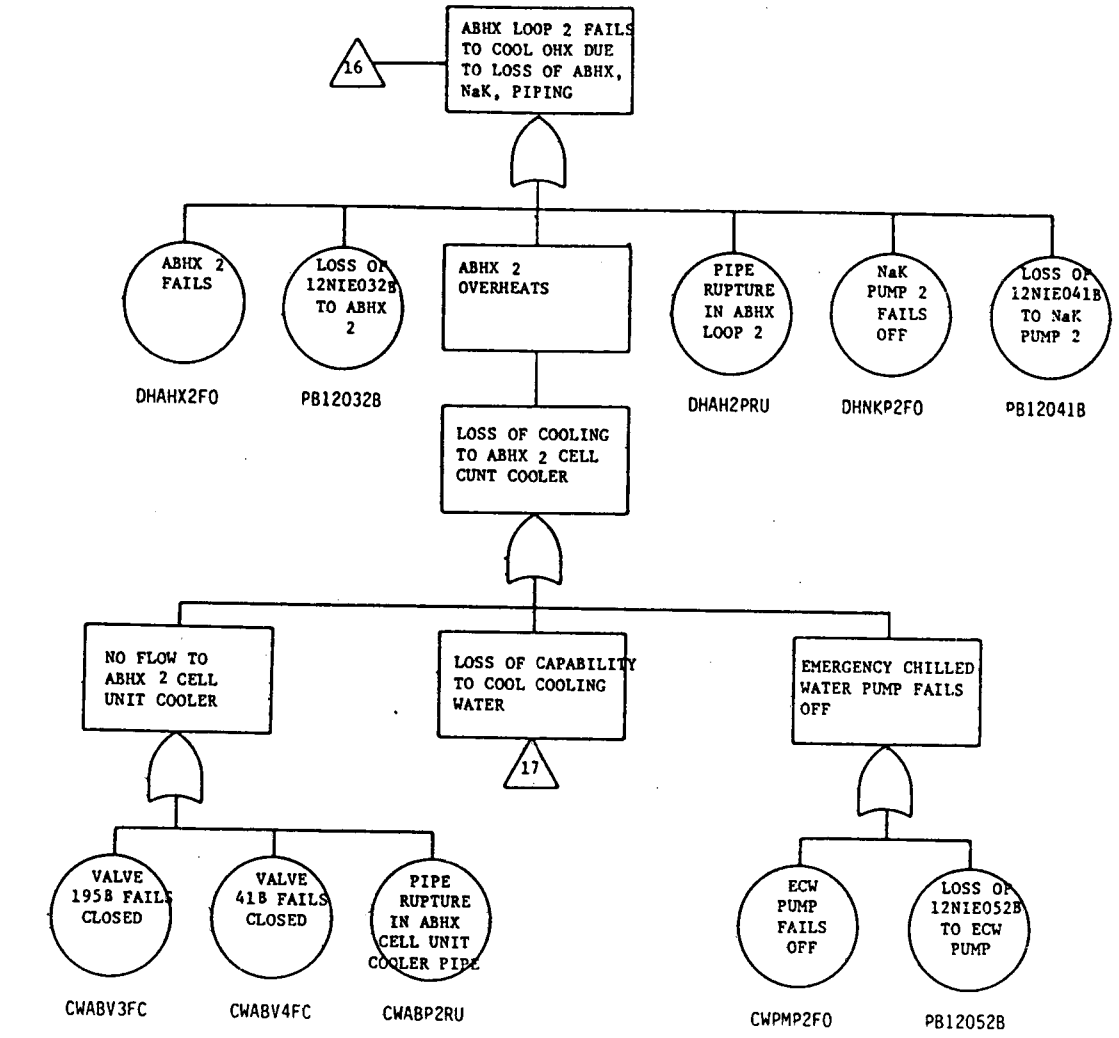

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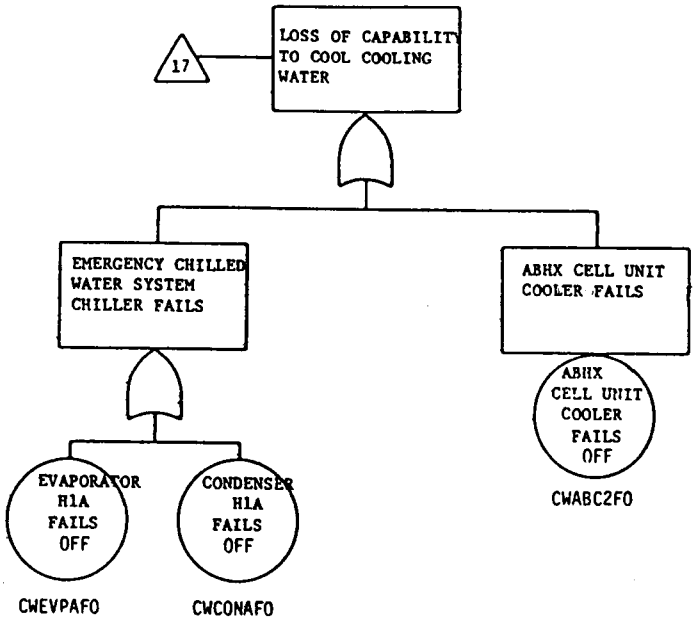

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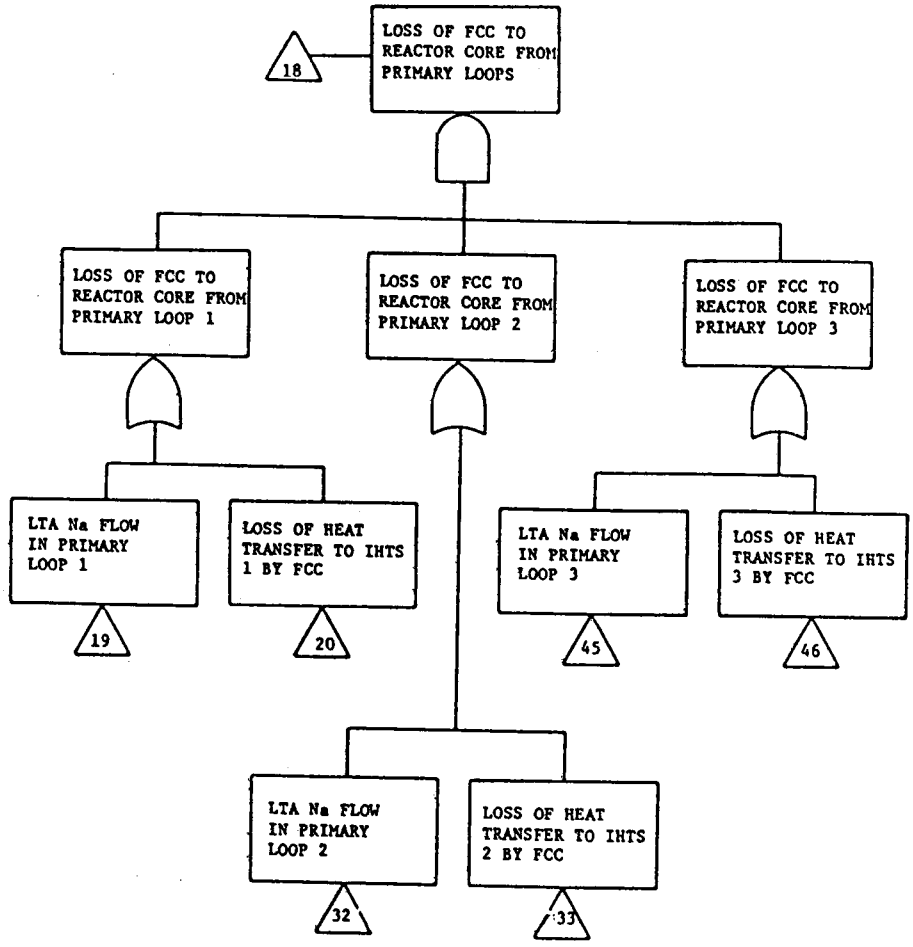

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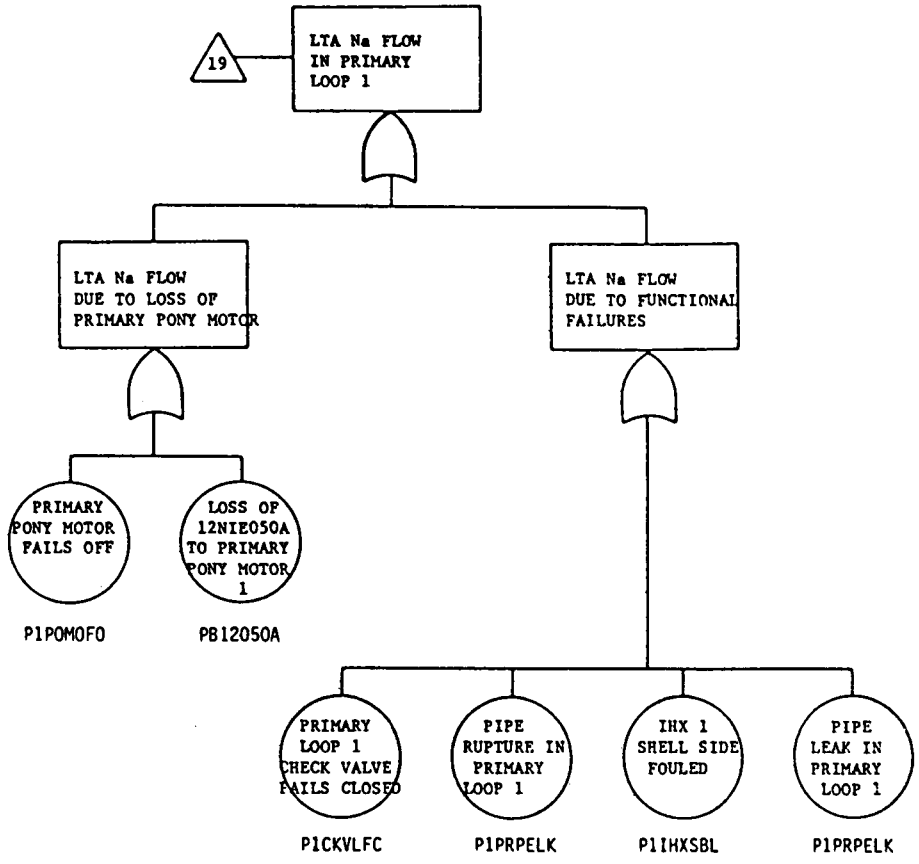

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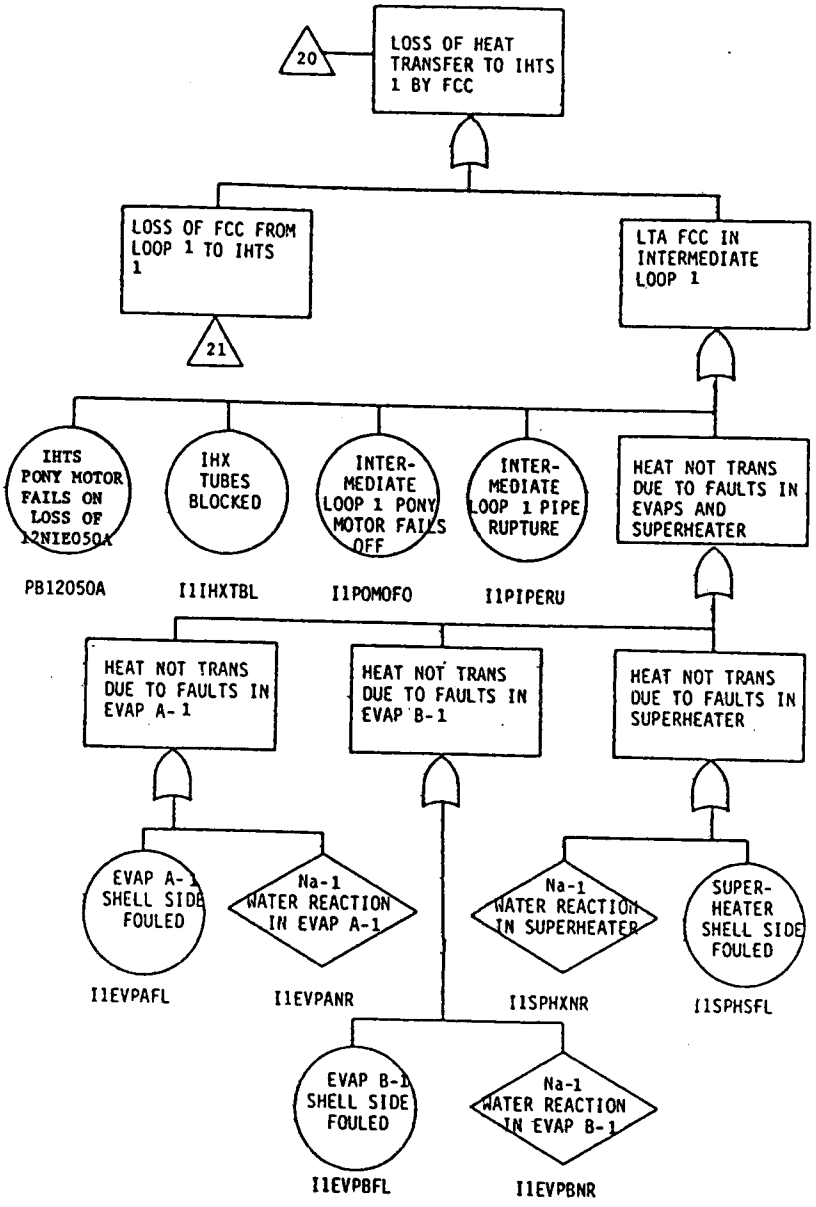

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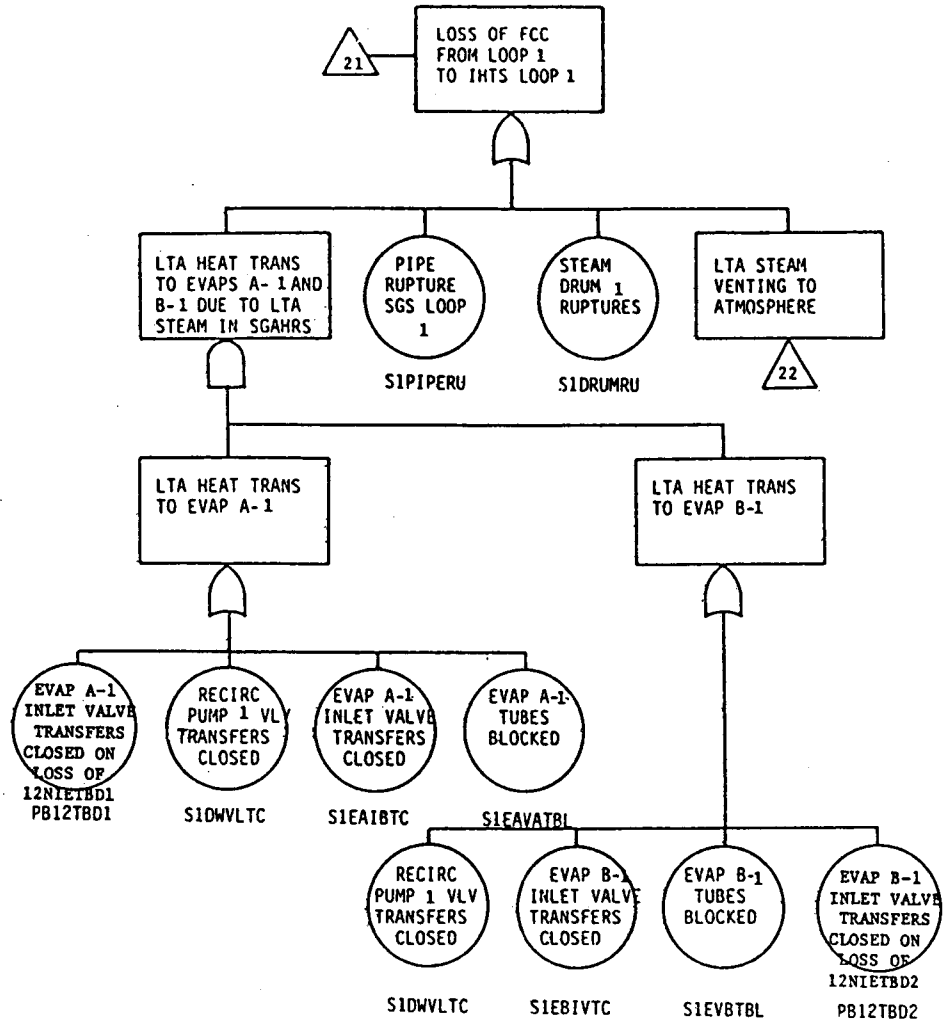

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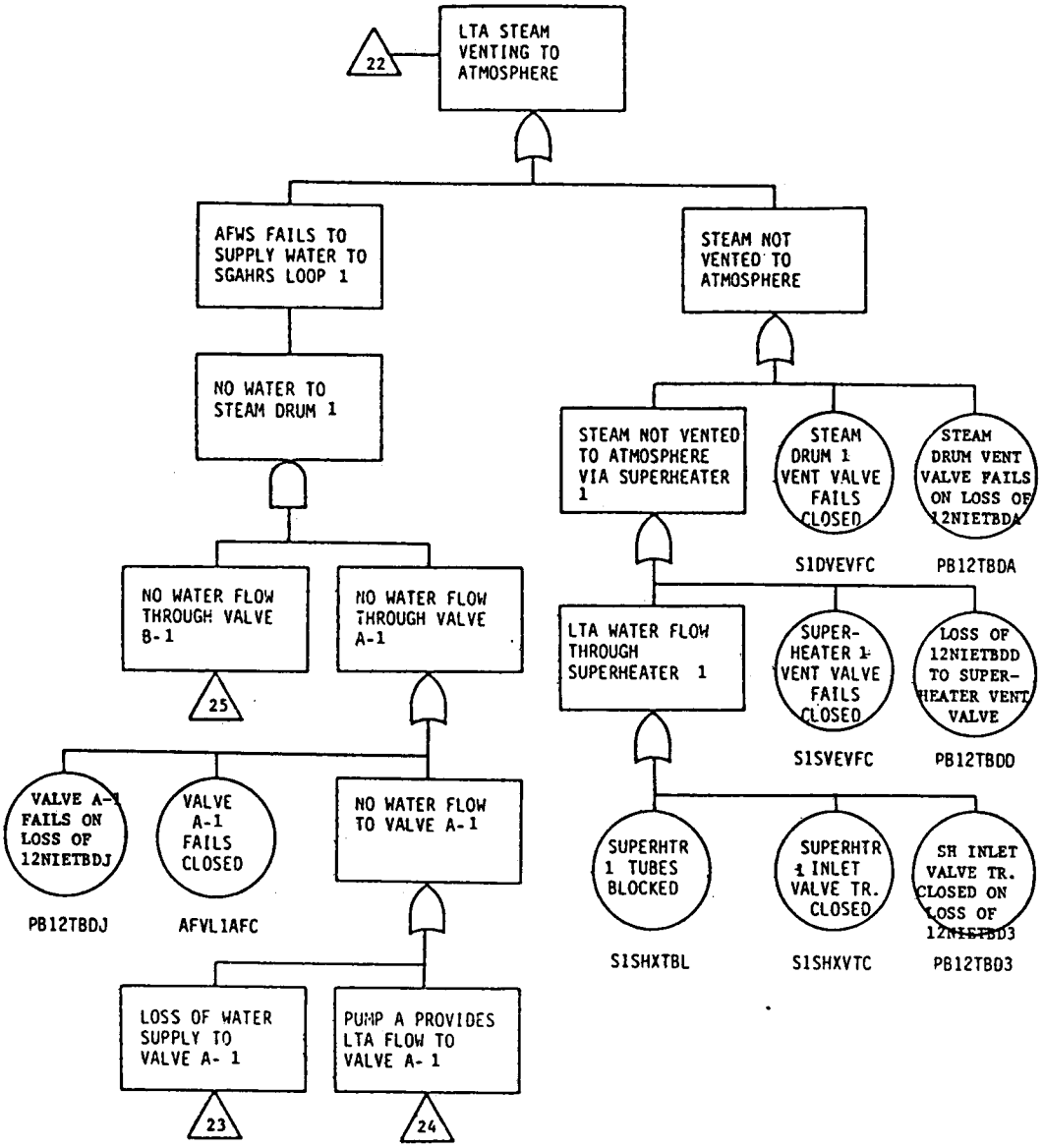

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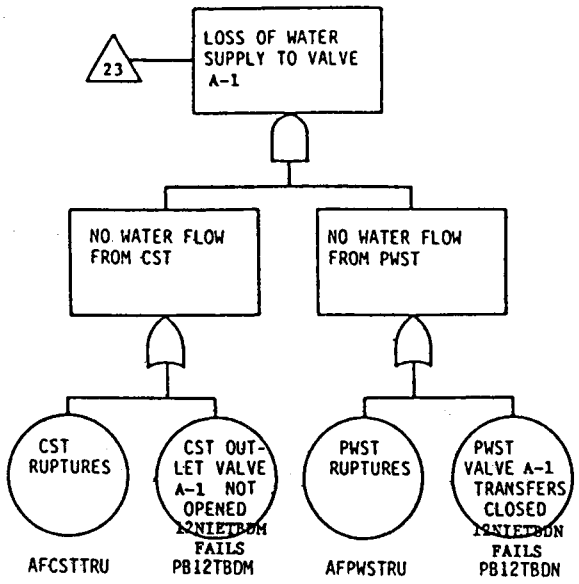

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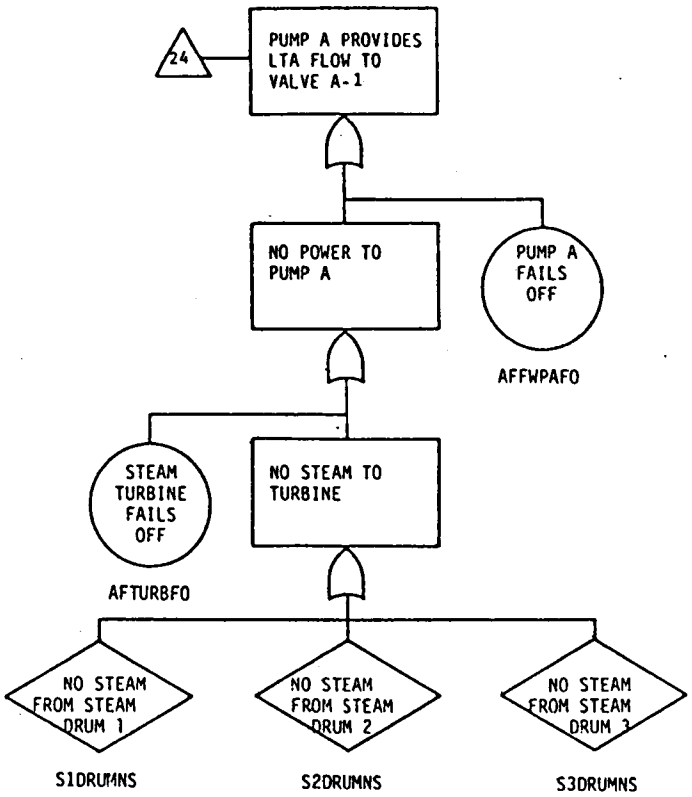

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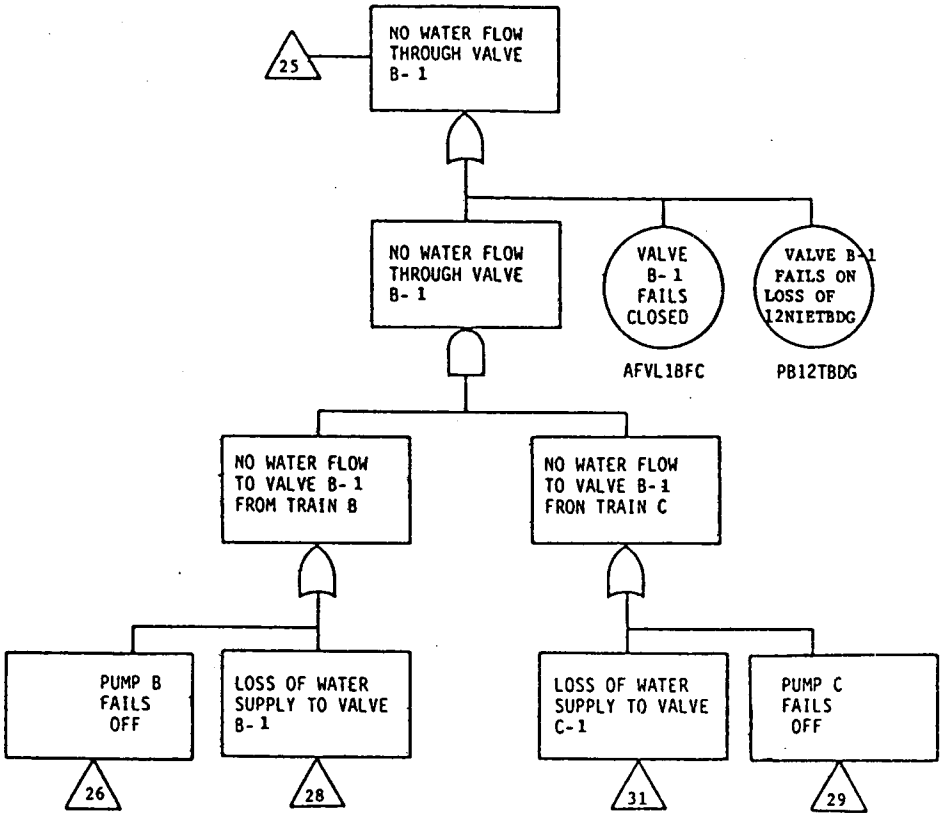

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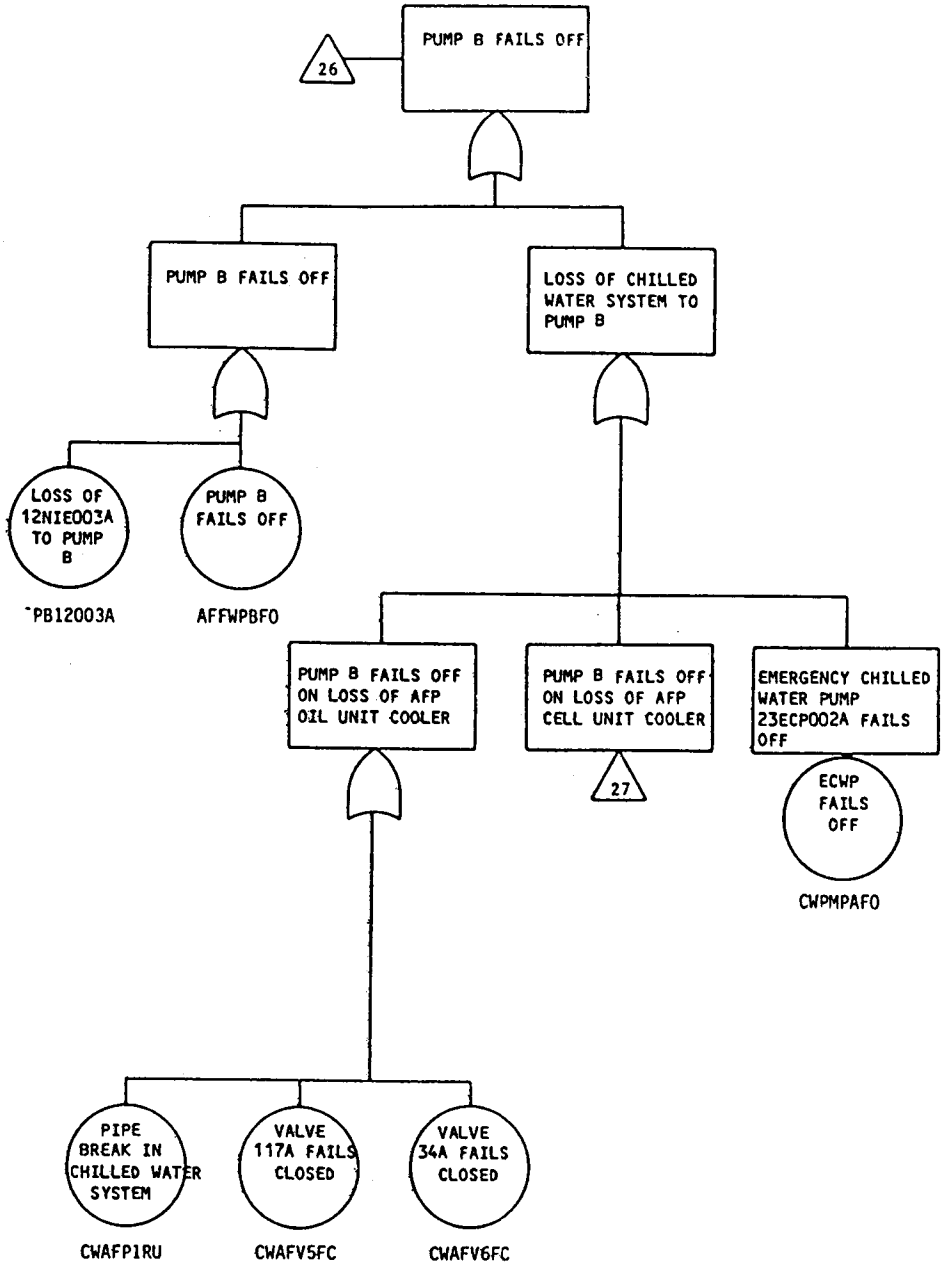

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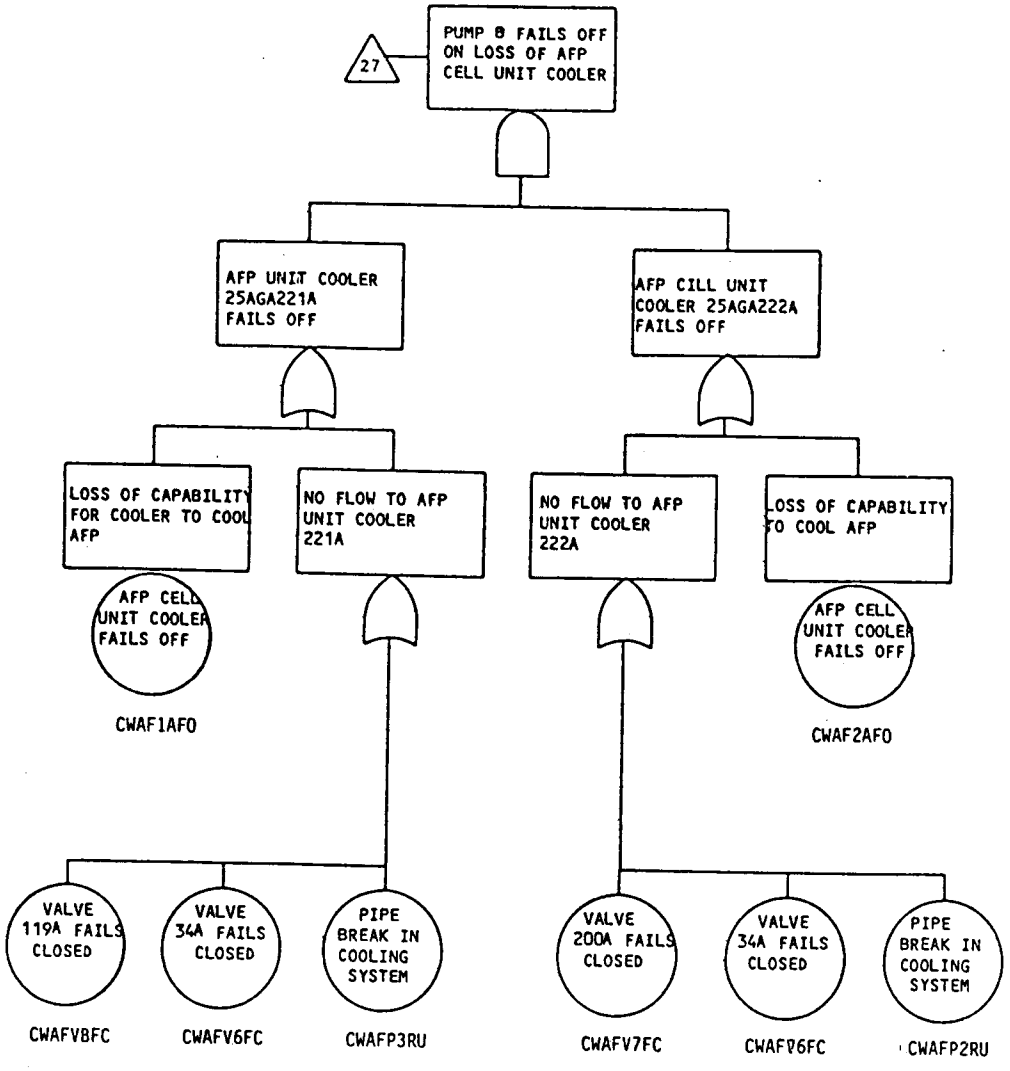

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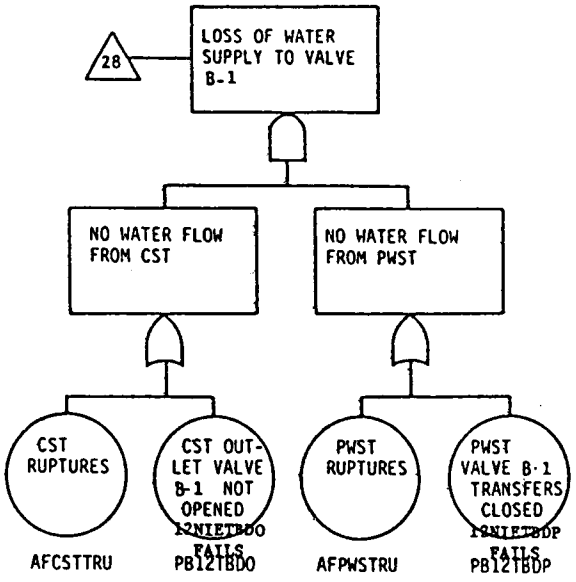

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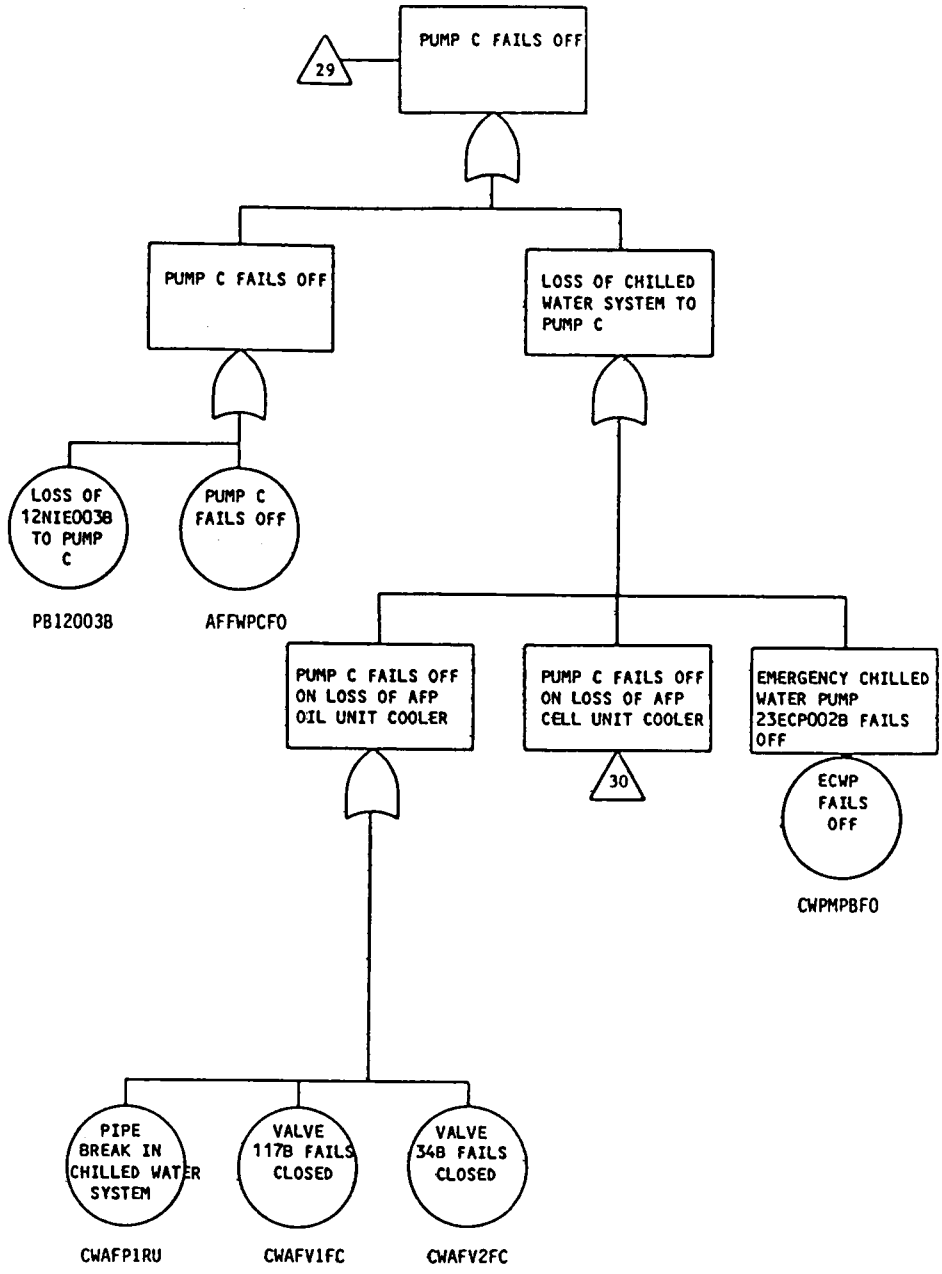

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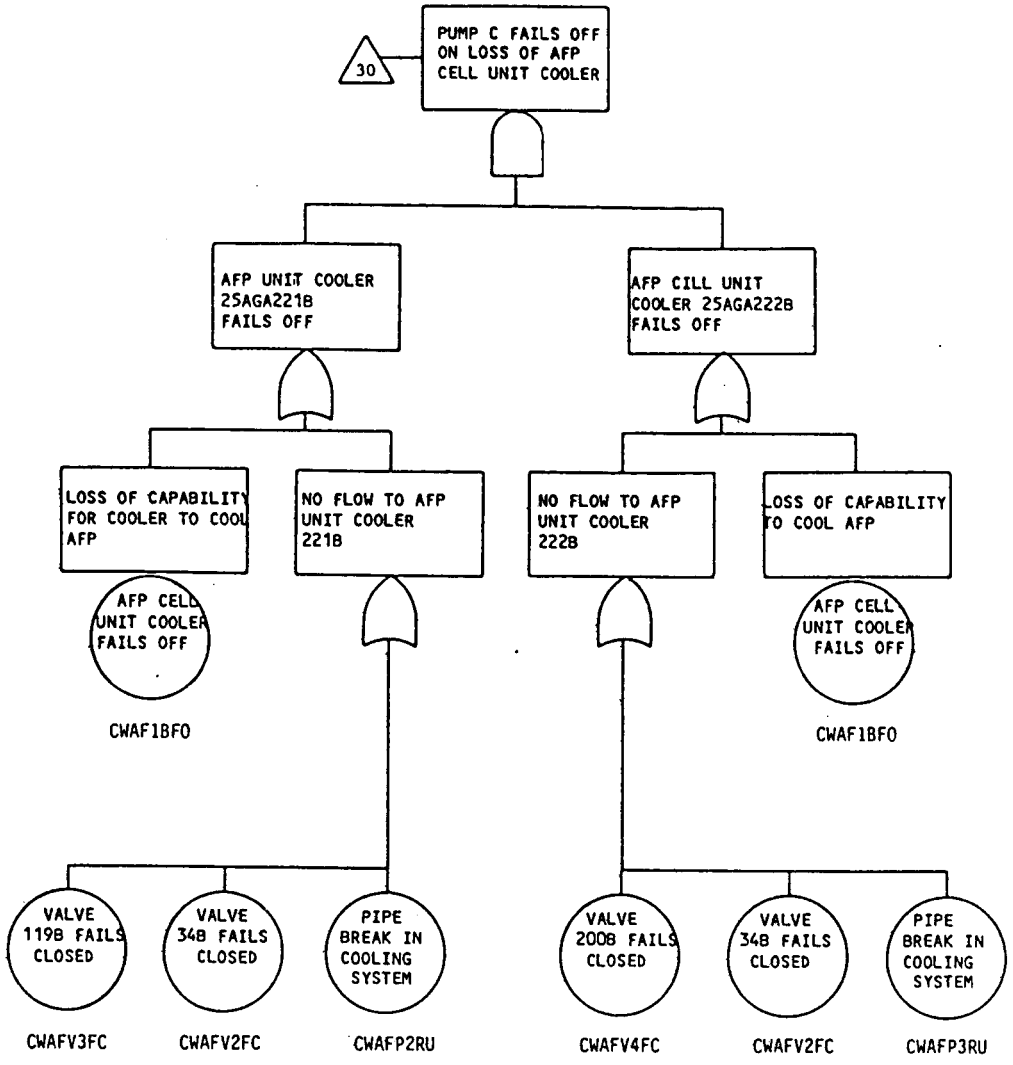

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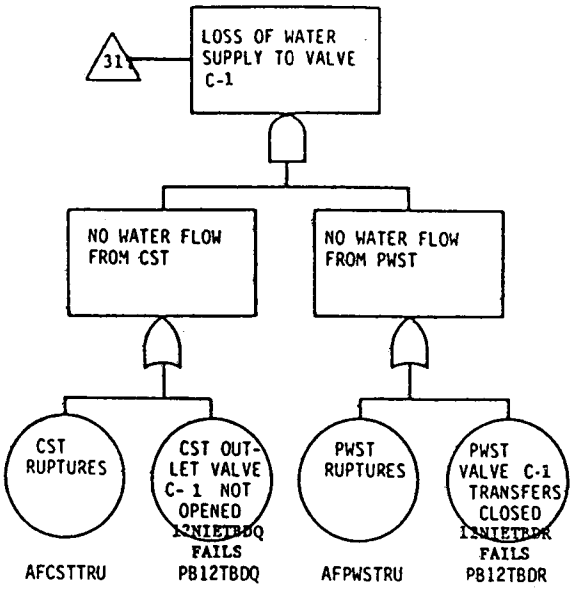

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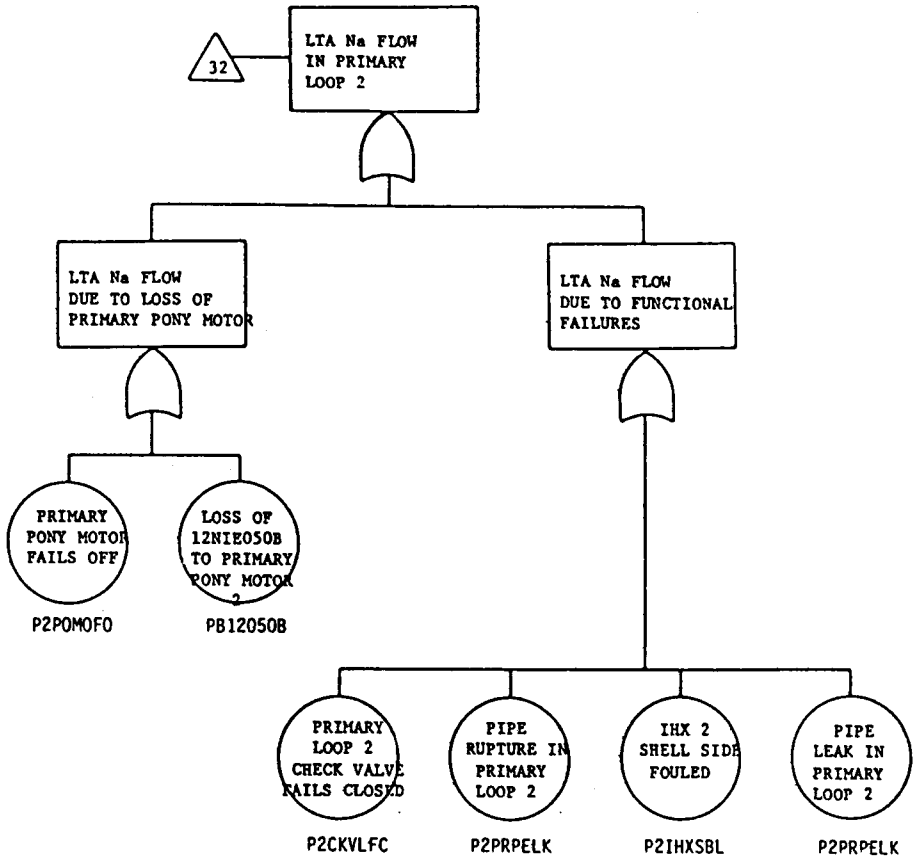

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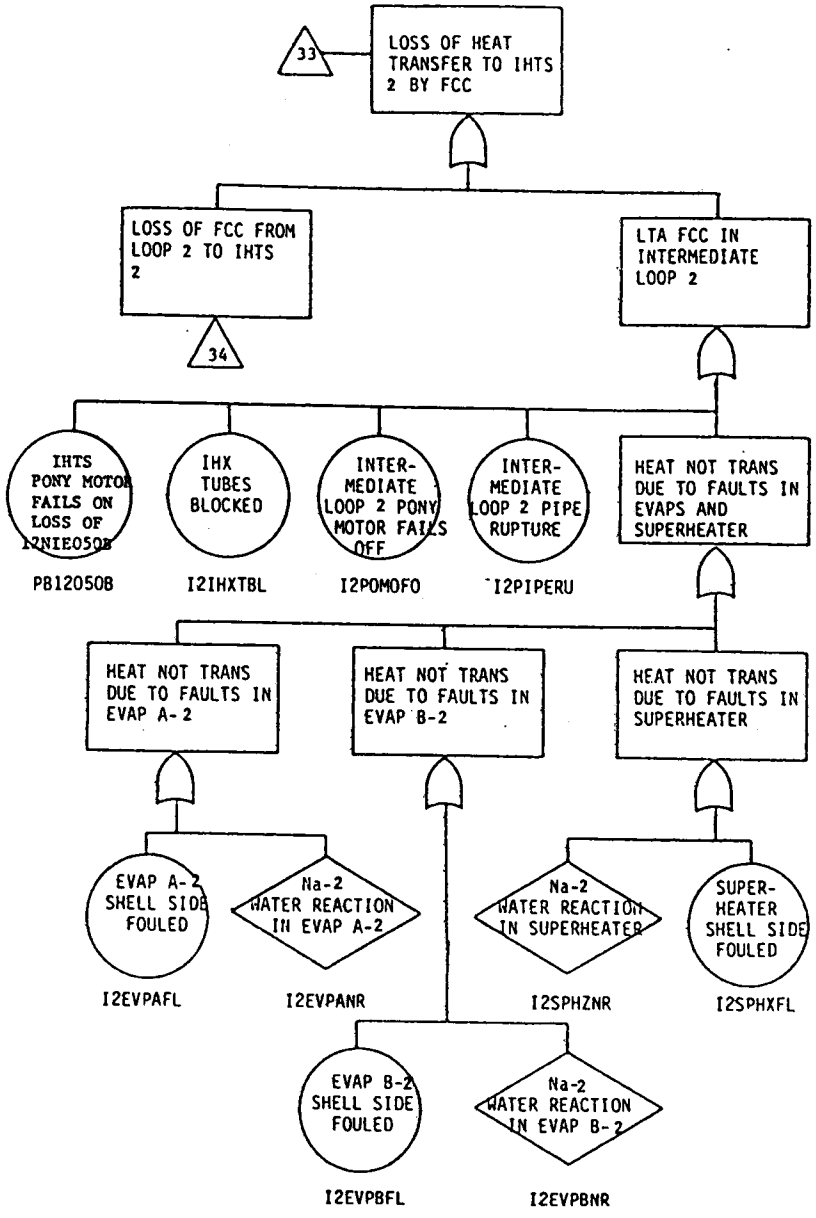

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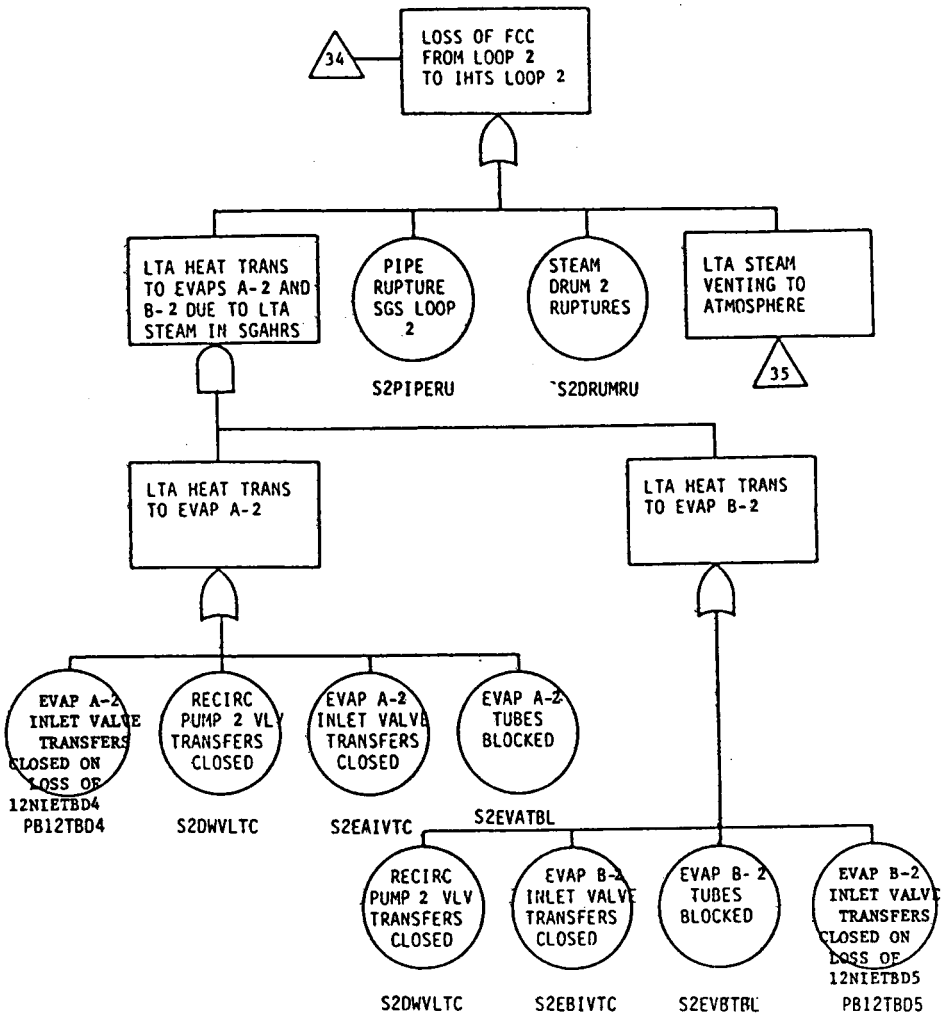

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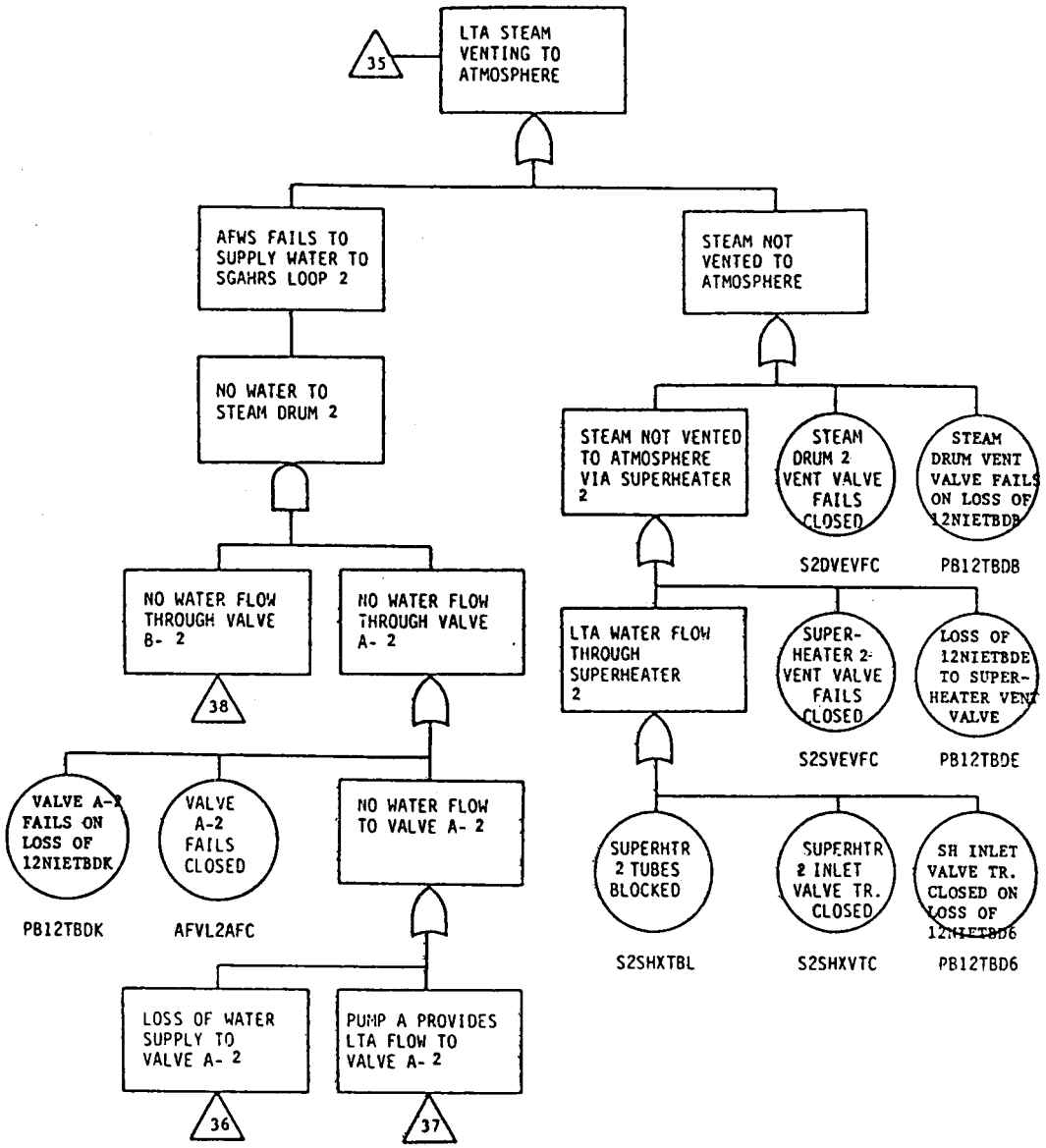

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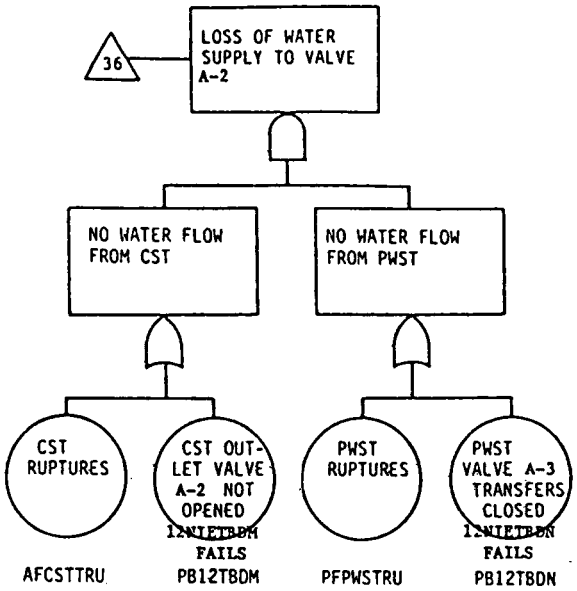

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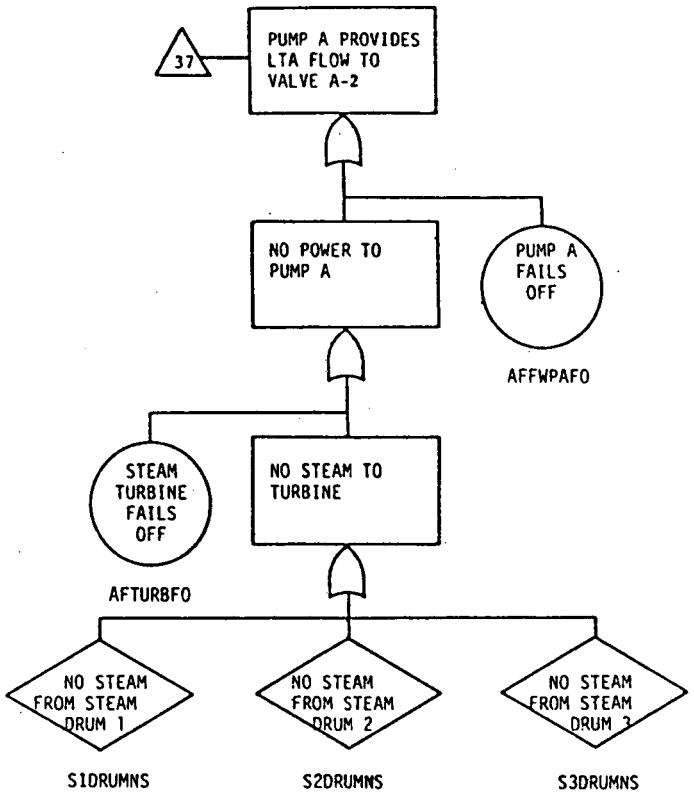

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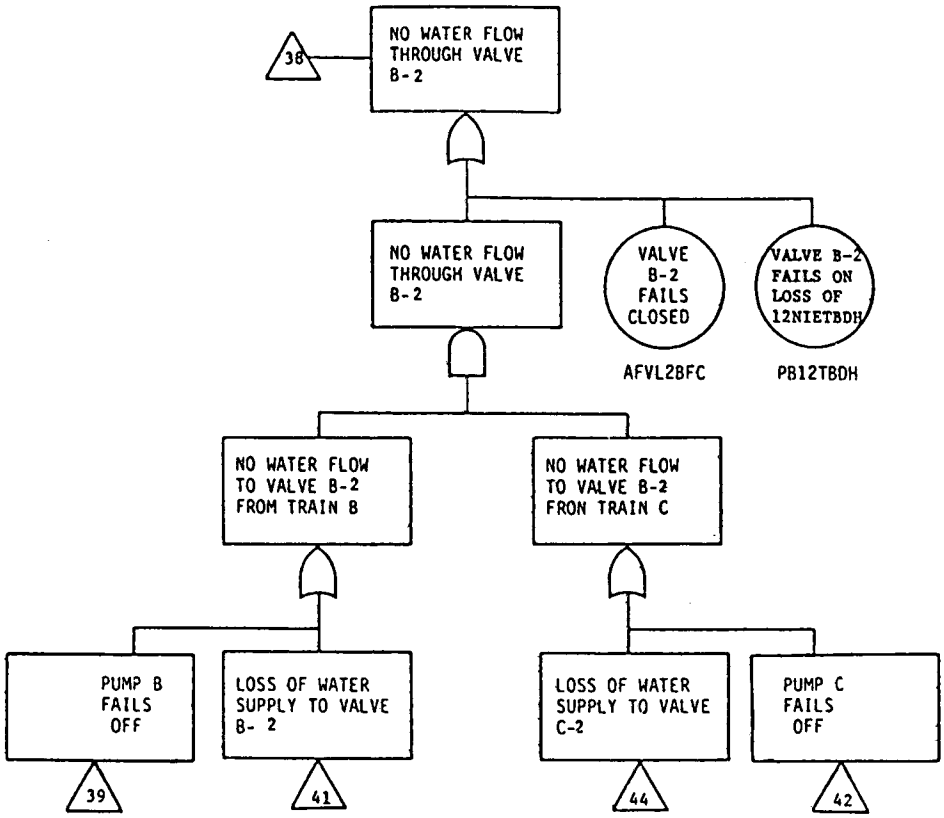

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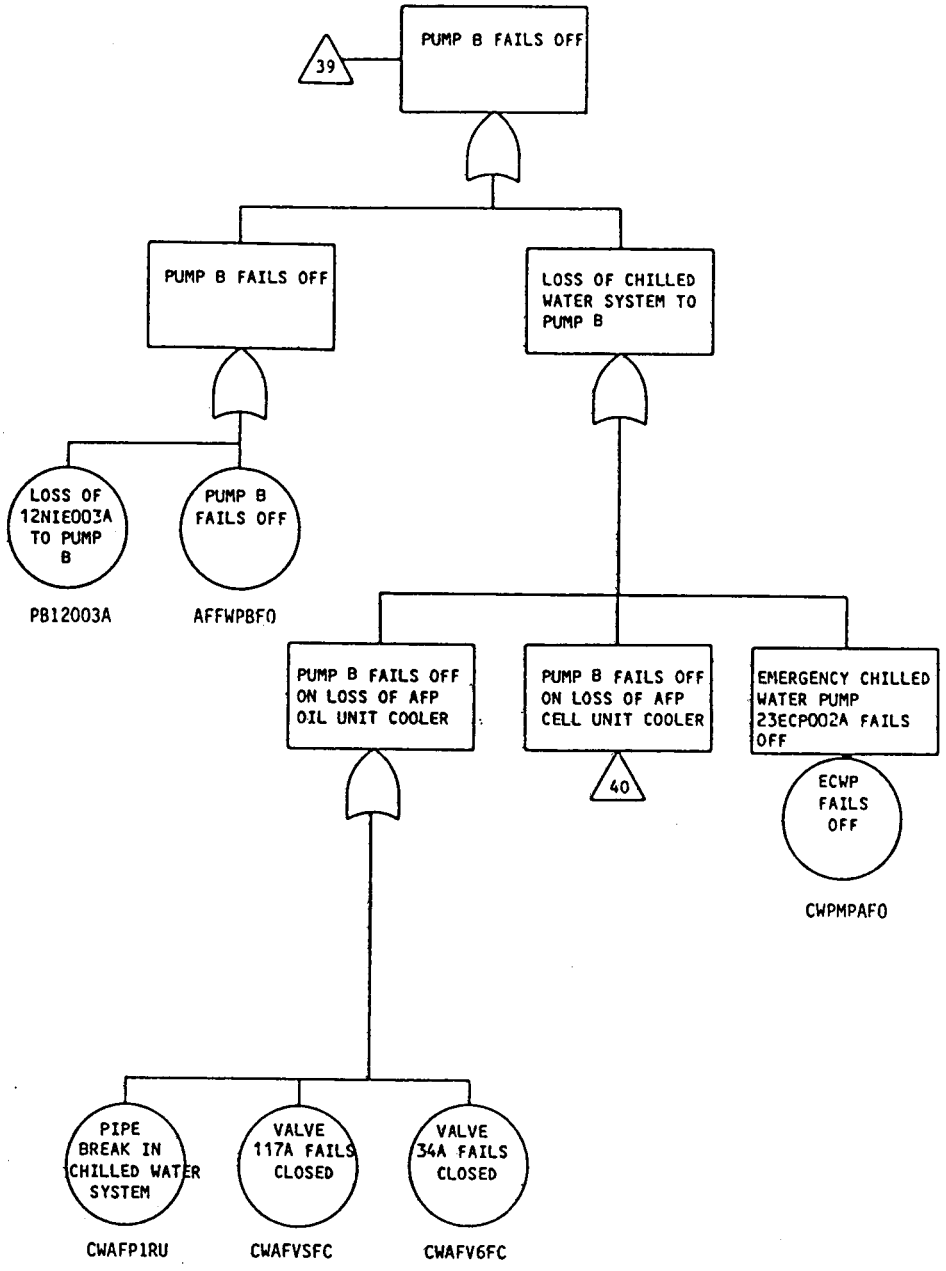

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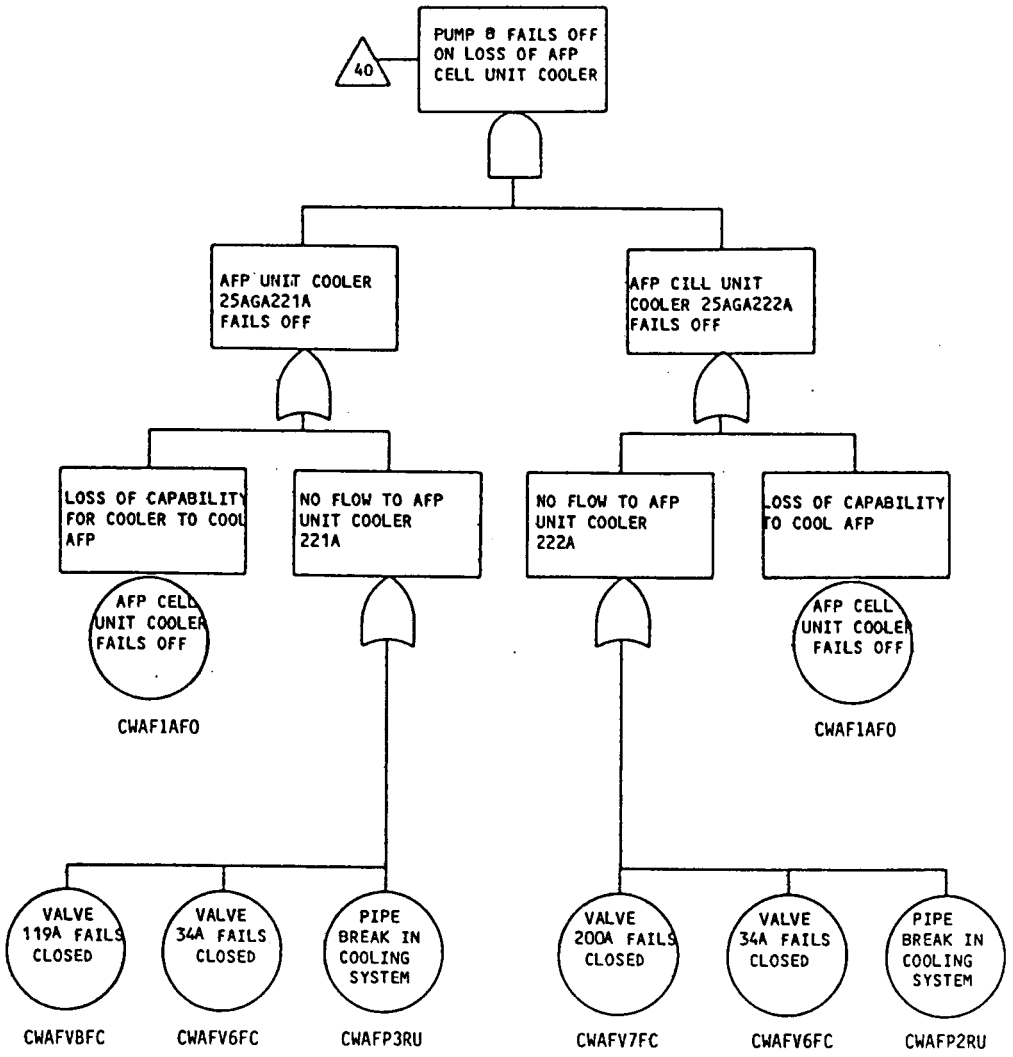

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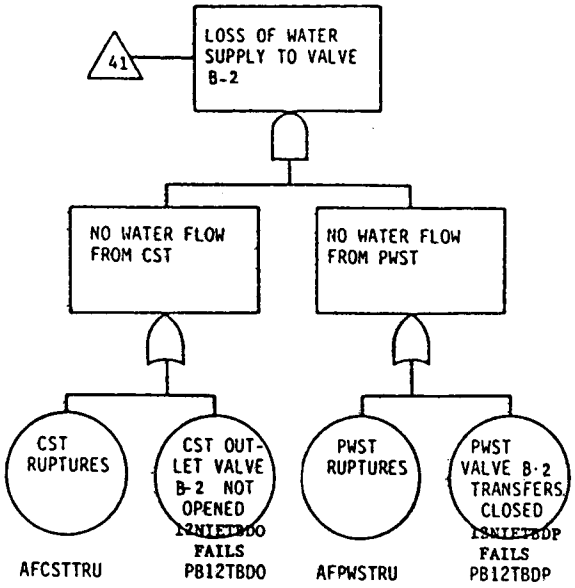

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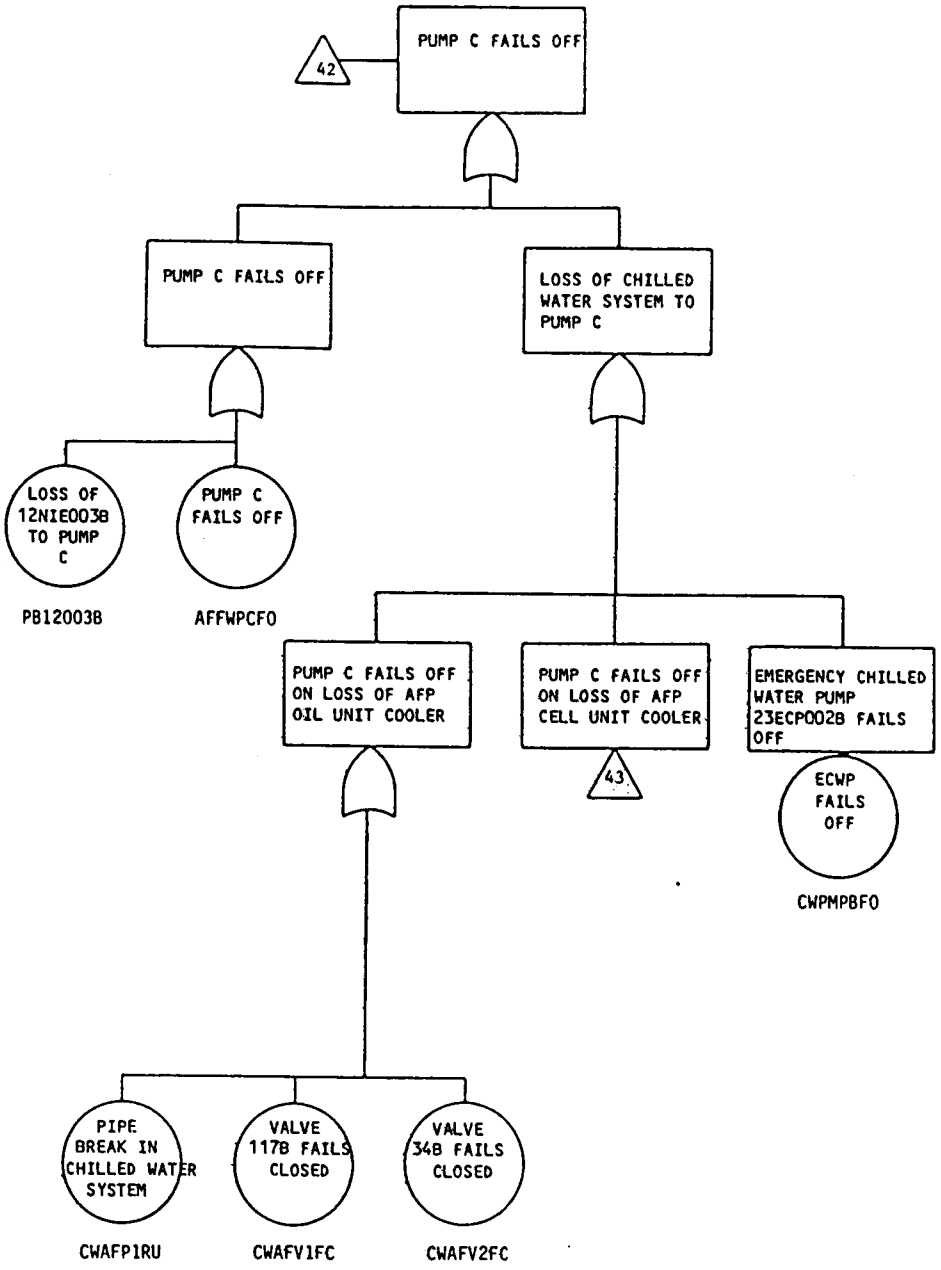

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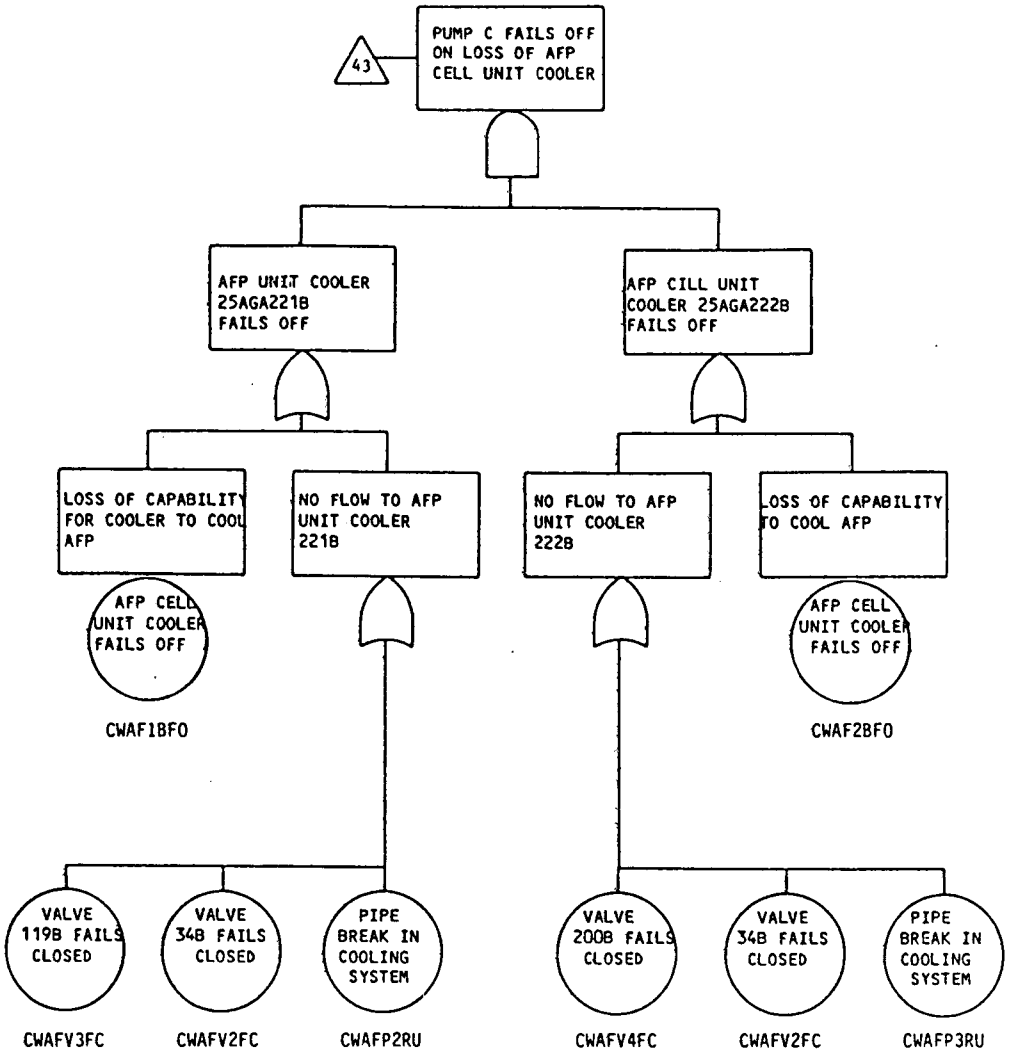

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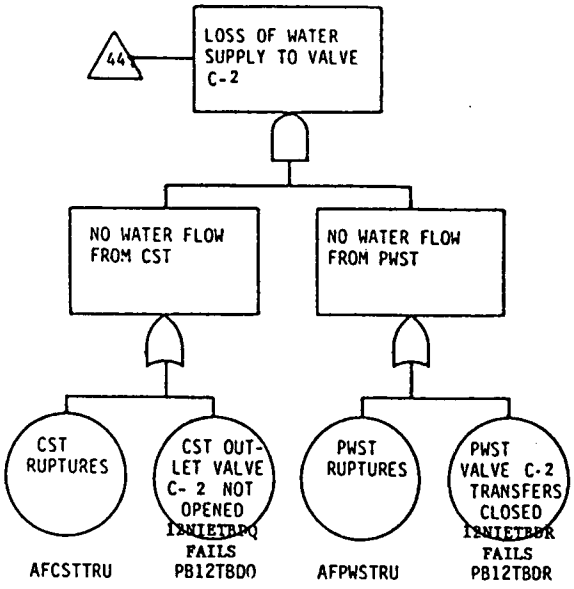

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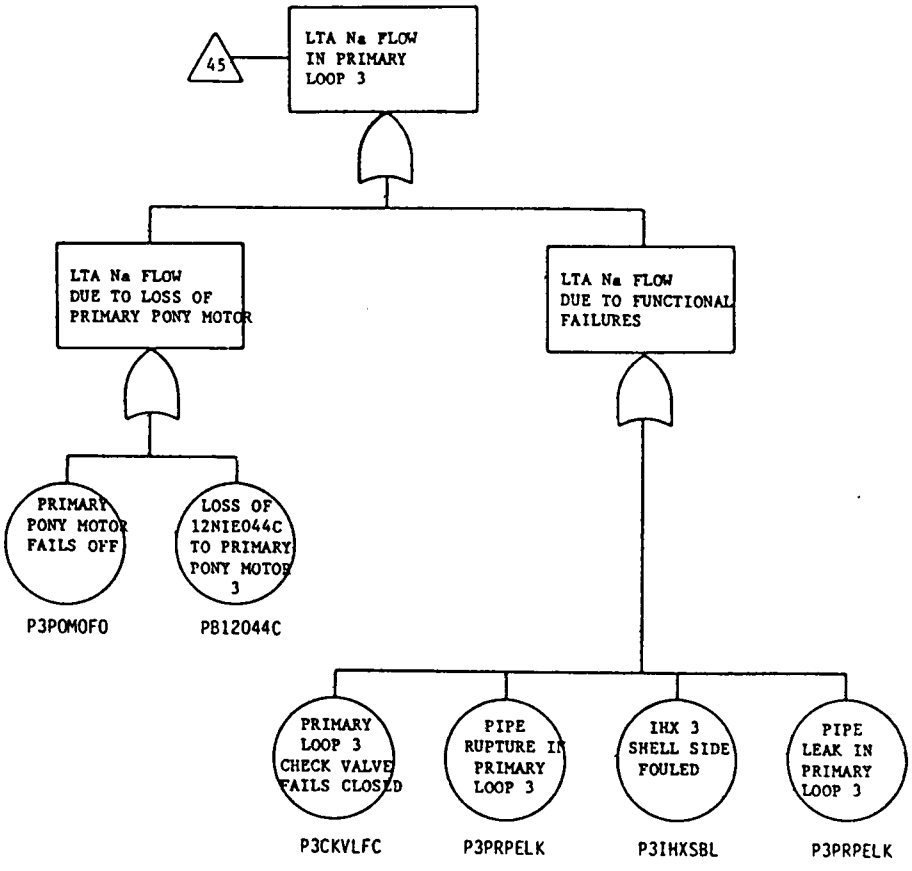

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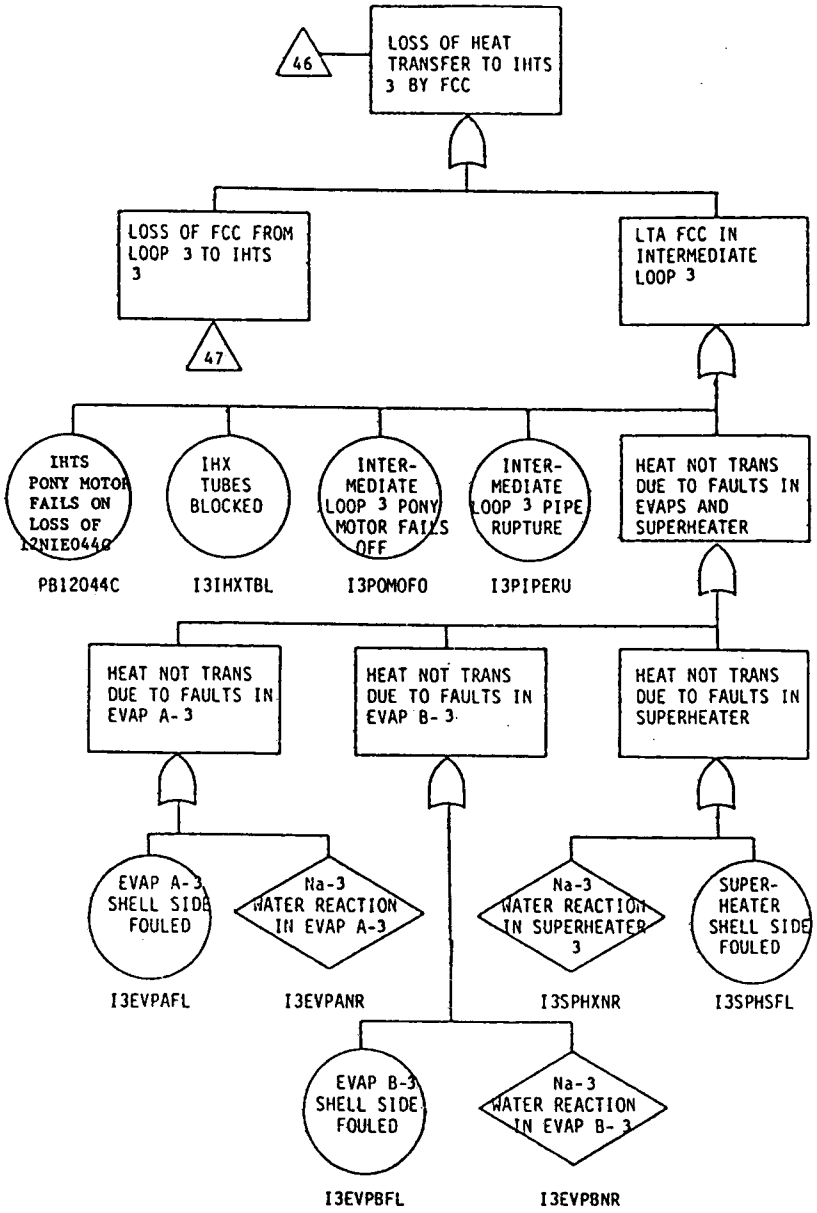

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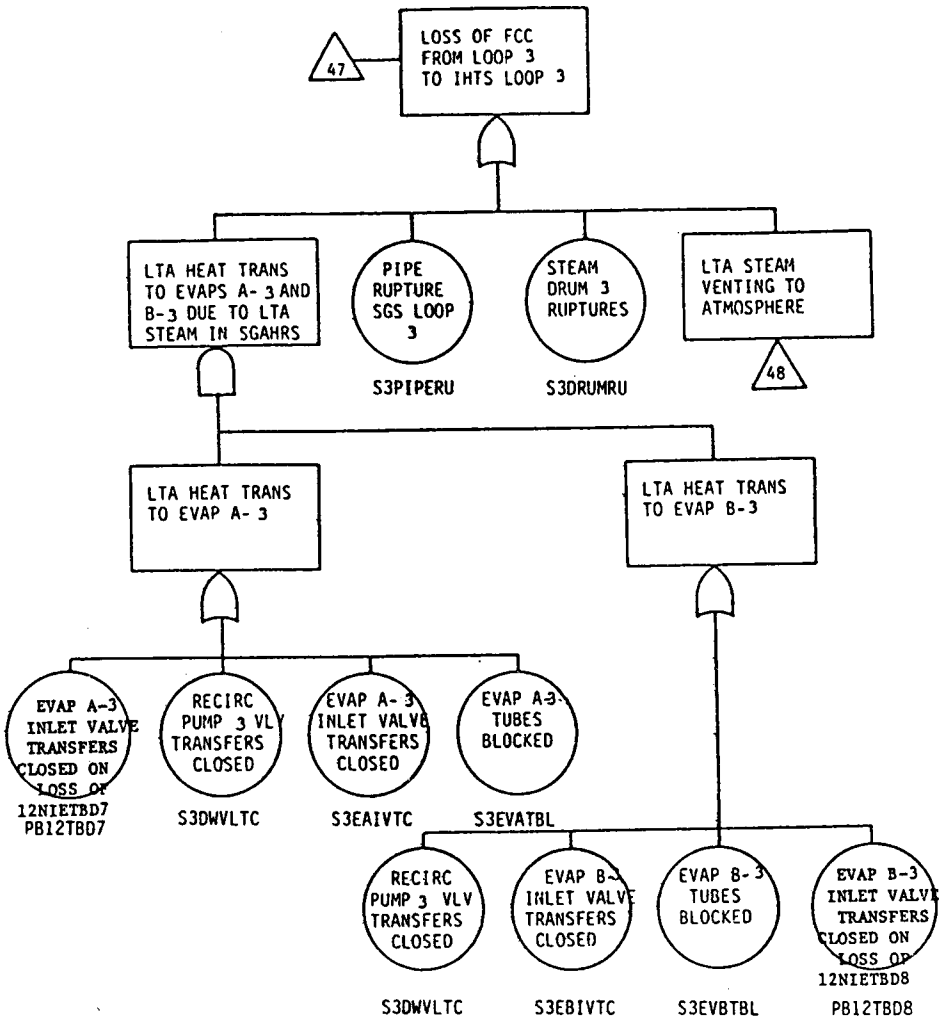

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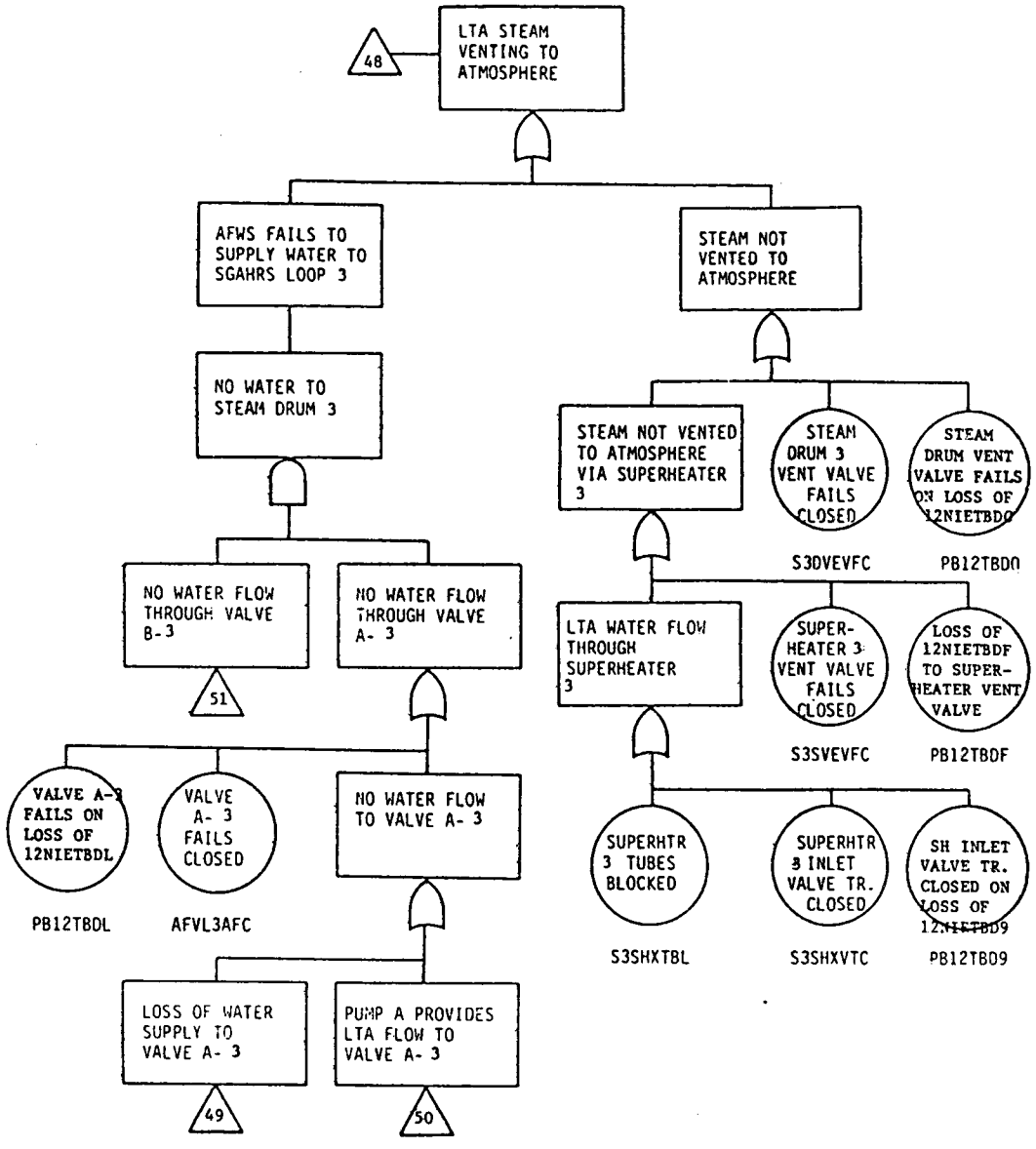

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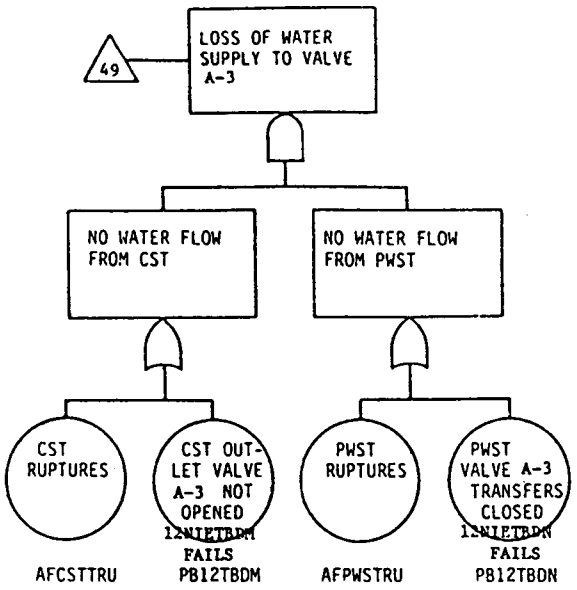

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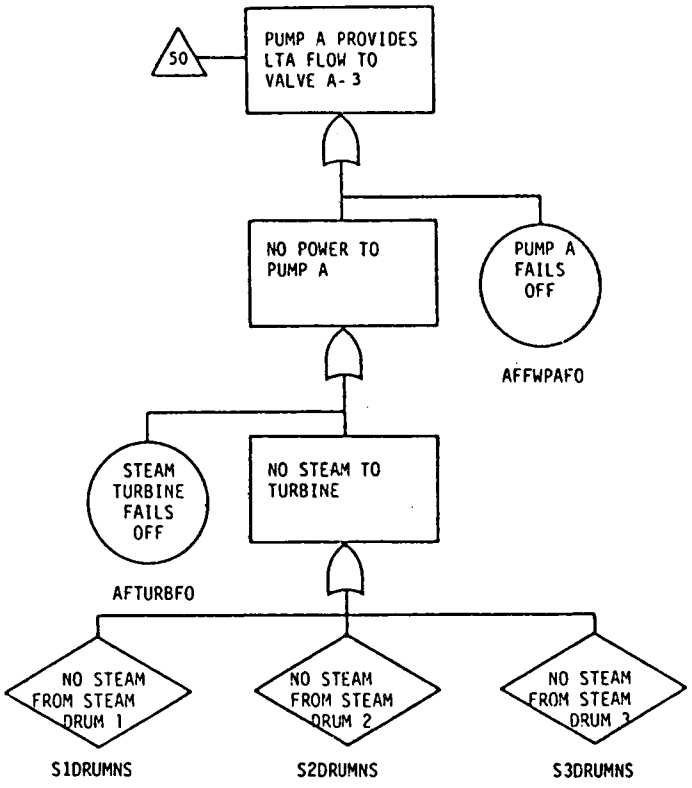

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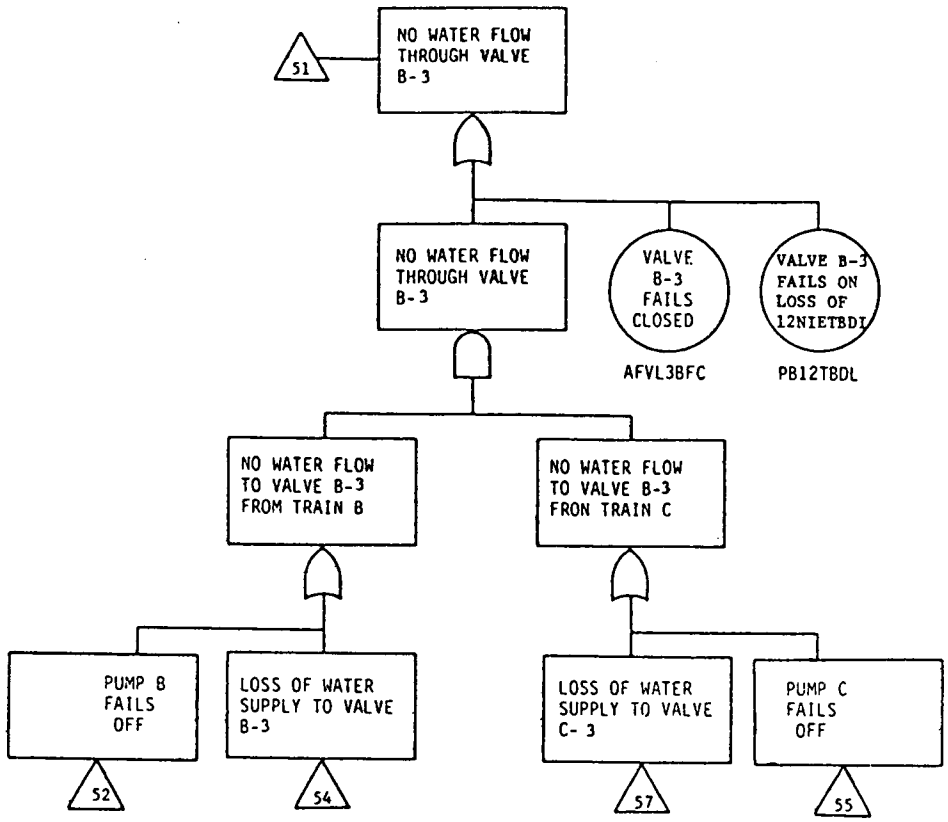

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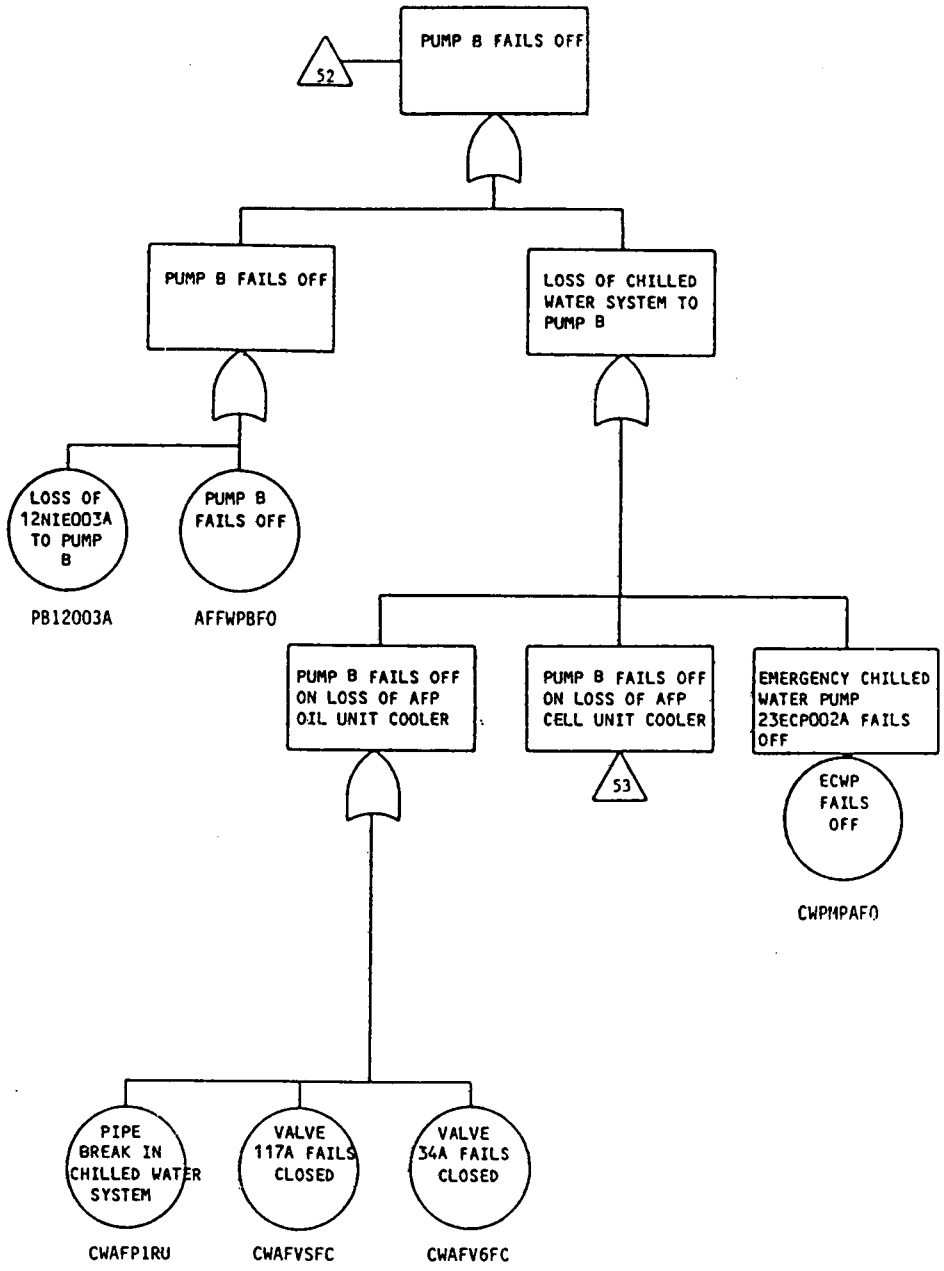

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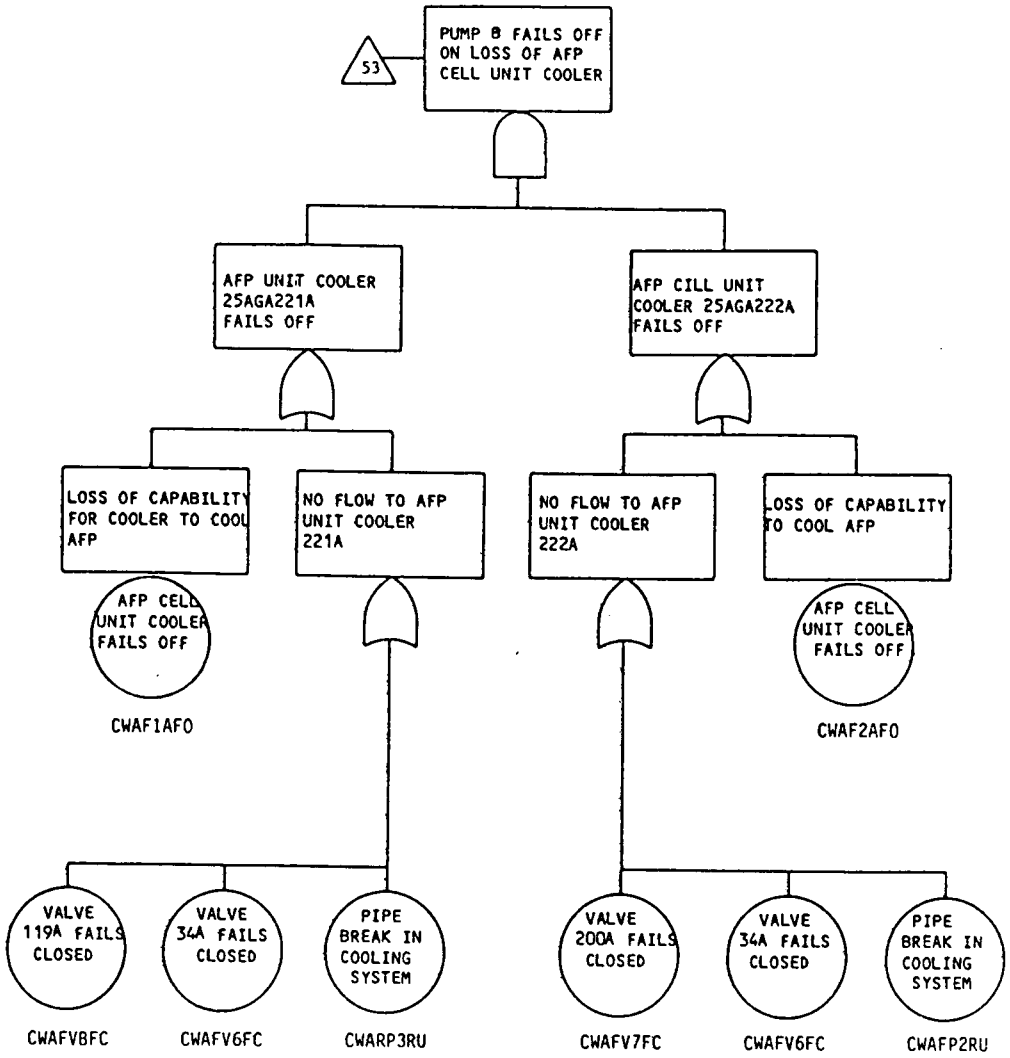

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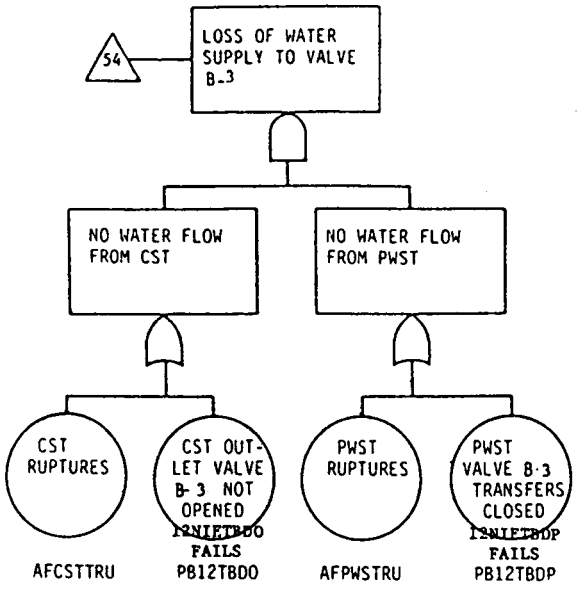

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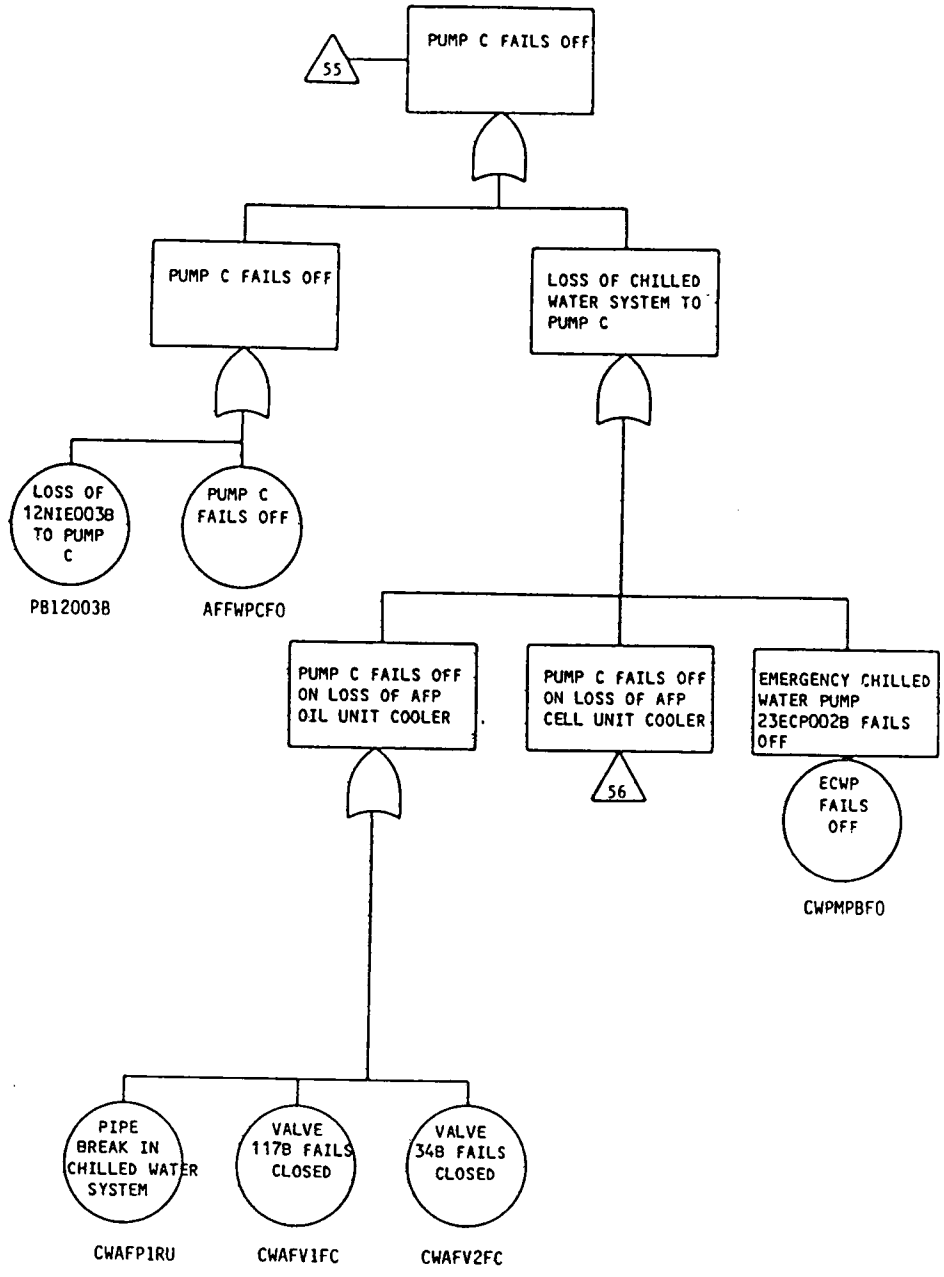

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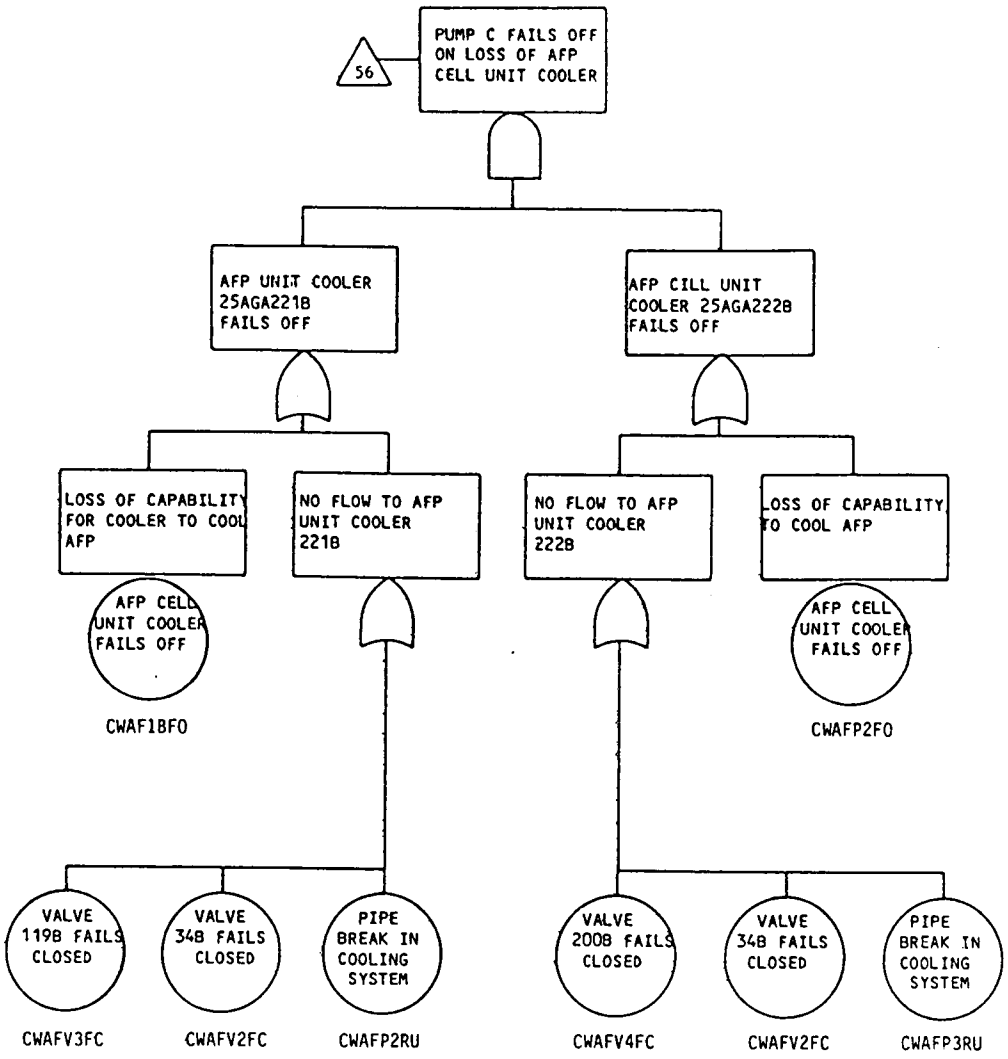

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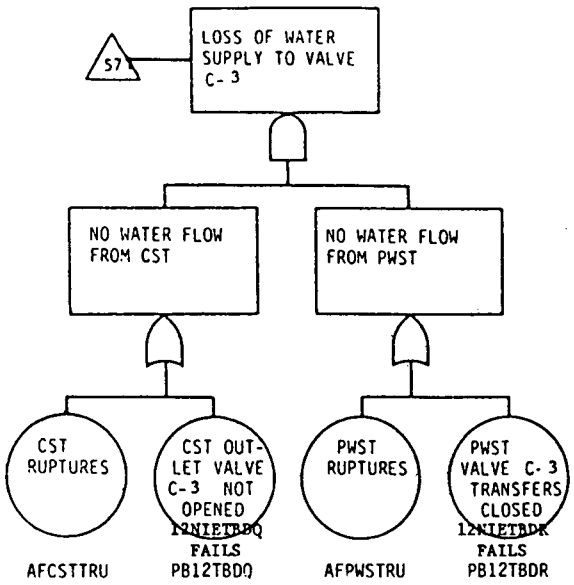


Figure C.1. .(continued).

APPENDIX D

CRBRP SHUTDOWN HEAT REMOVAL SYSTEM SYSTEMS INTERACTION FAULT TREE AT THE SECONDARY INTERFACE LEVEL

CRBRP SHUTDOWN HEAT REMOVAL SYSTEM SYSTEMS INTERACTION FAULT TREE AT THE SECONDARY INTERFACE LEVEL

The CRBRP SHRS logic models were developed in the fault tree format. A fault tree is a graphical representation of the failure logic of a system to a particular TOP event.

The logic model for the CRBRP SHRS at the secondary interface level is presented in Figure D.1.

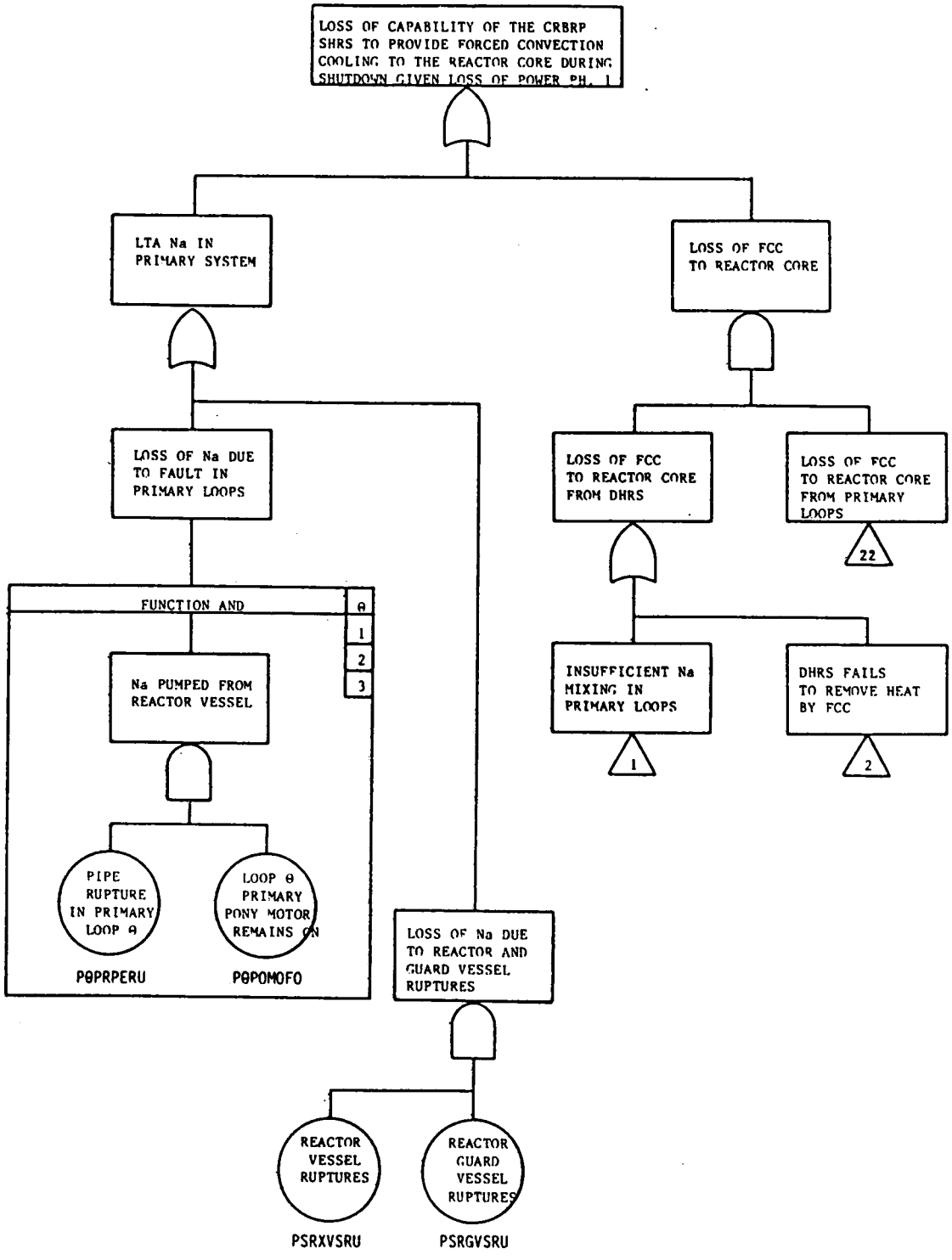
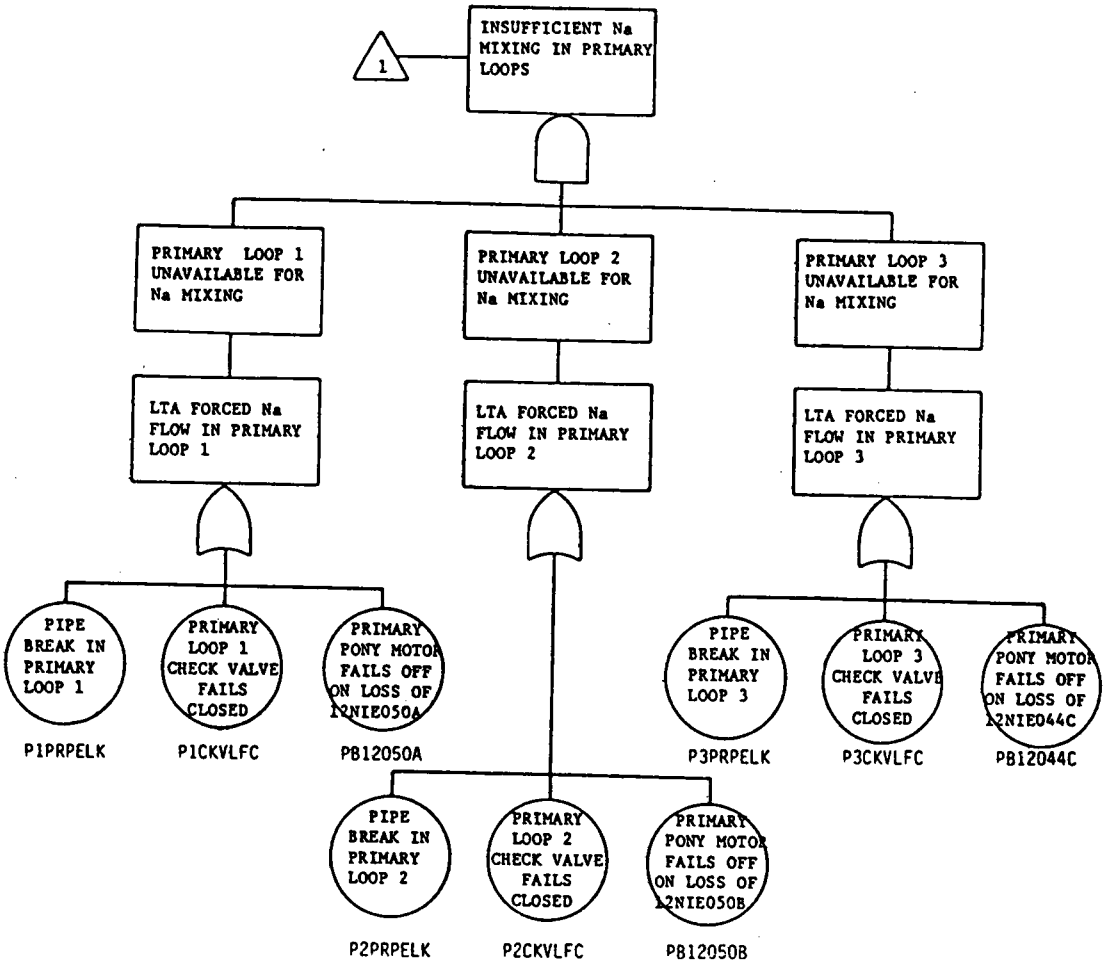


Figure D.1. CRBRP Shutdown Heat Removal System systems interaction fault tree at the secondary interface level.



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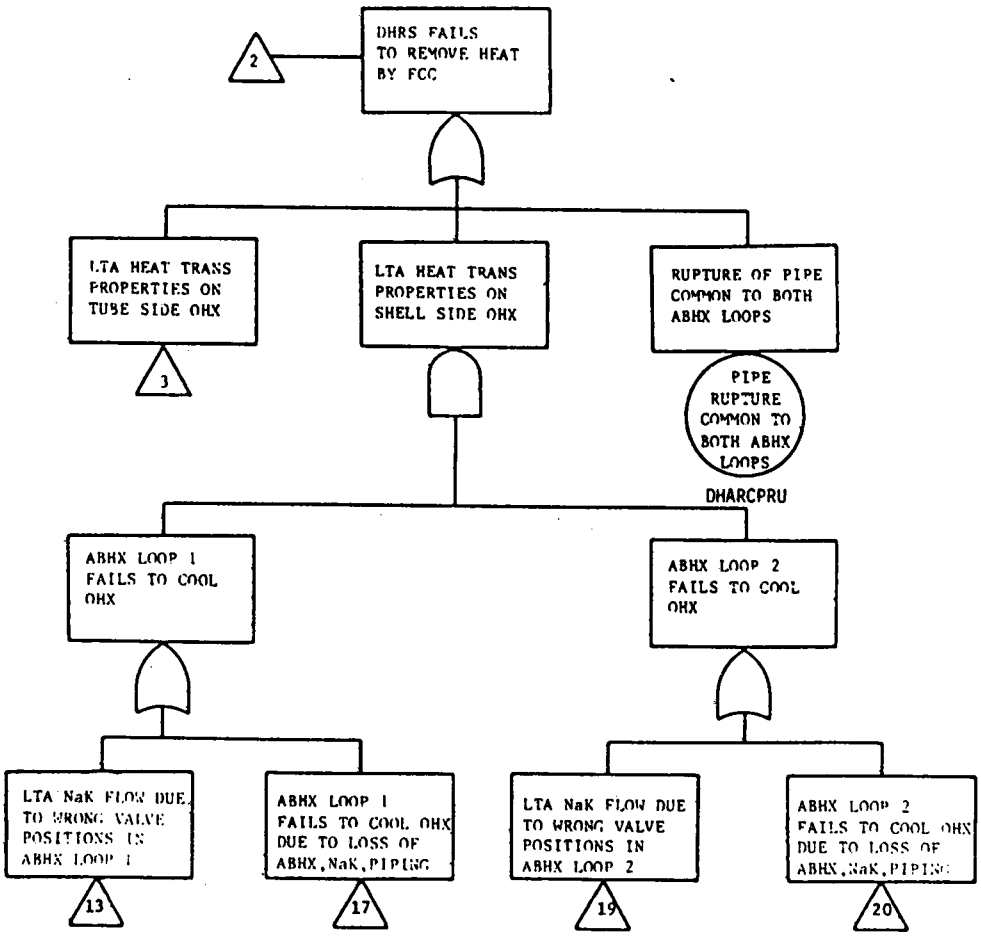

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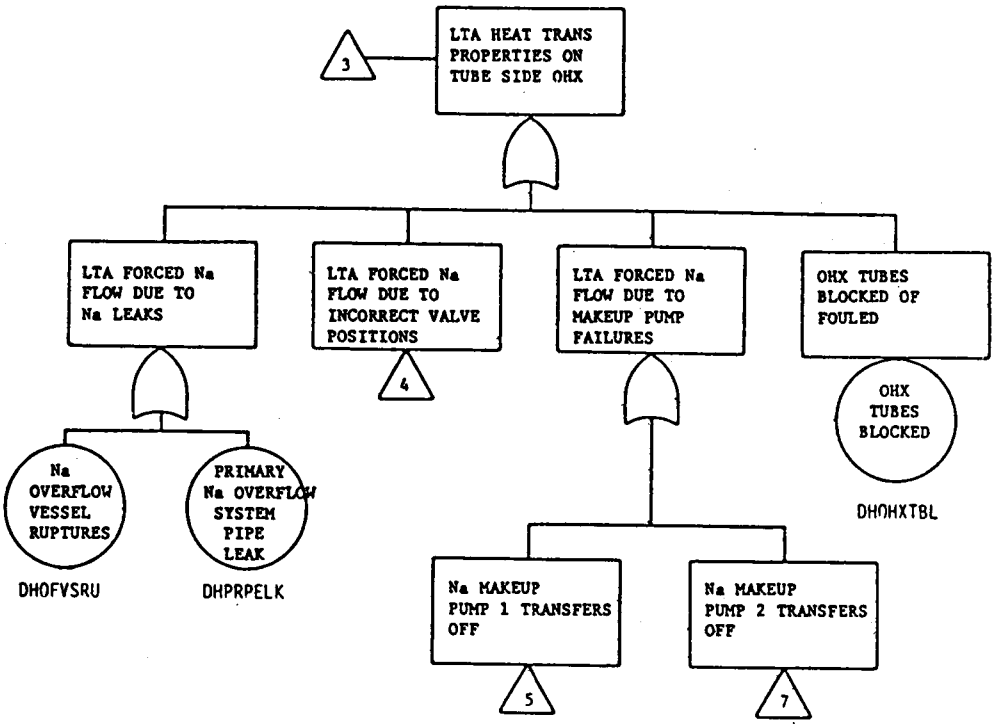

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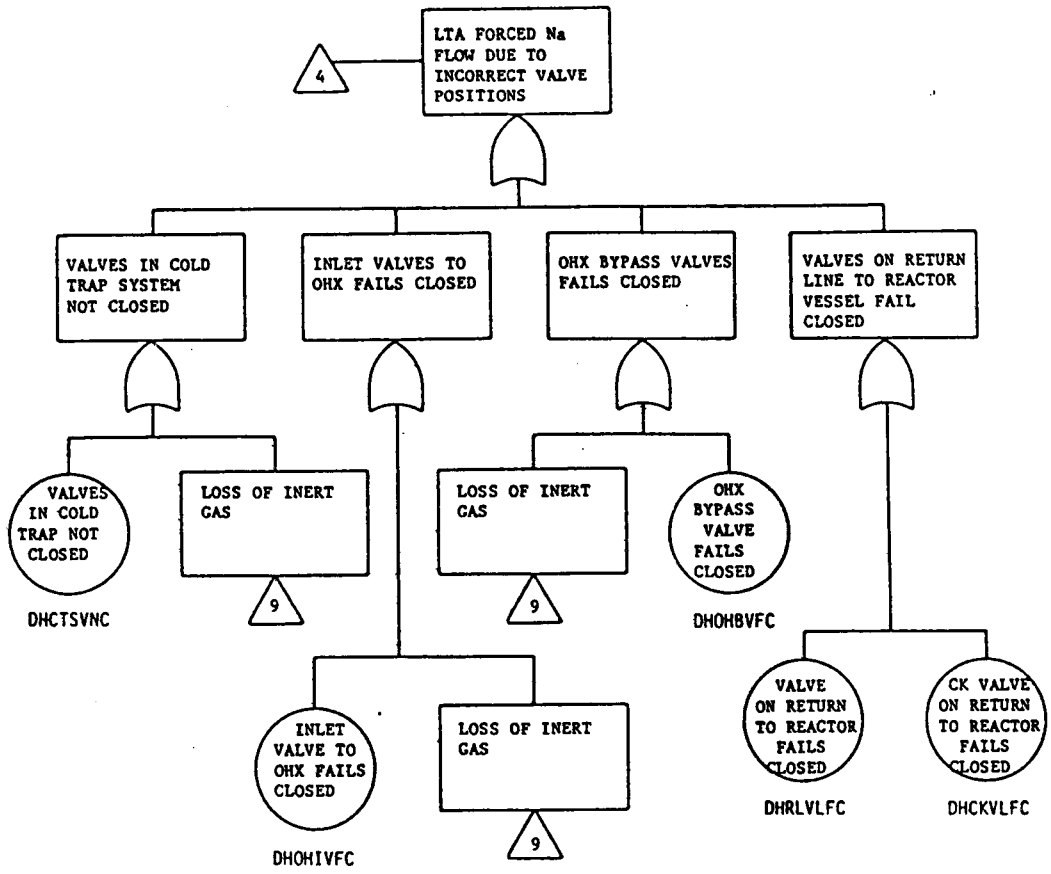

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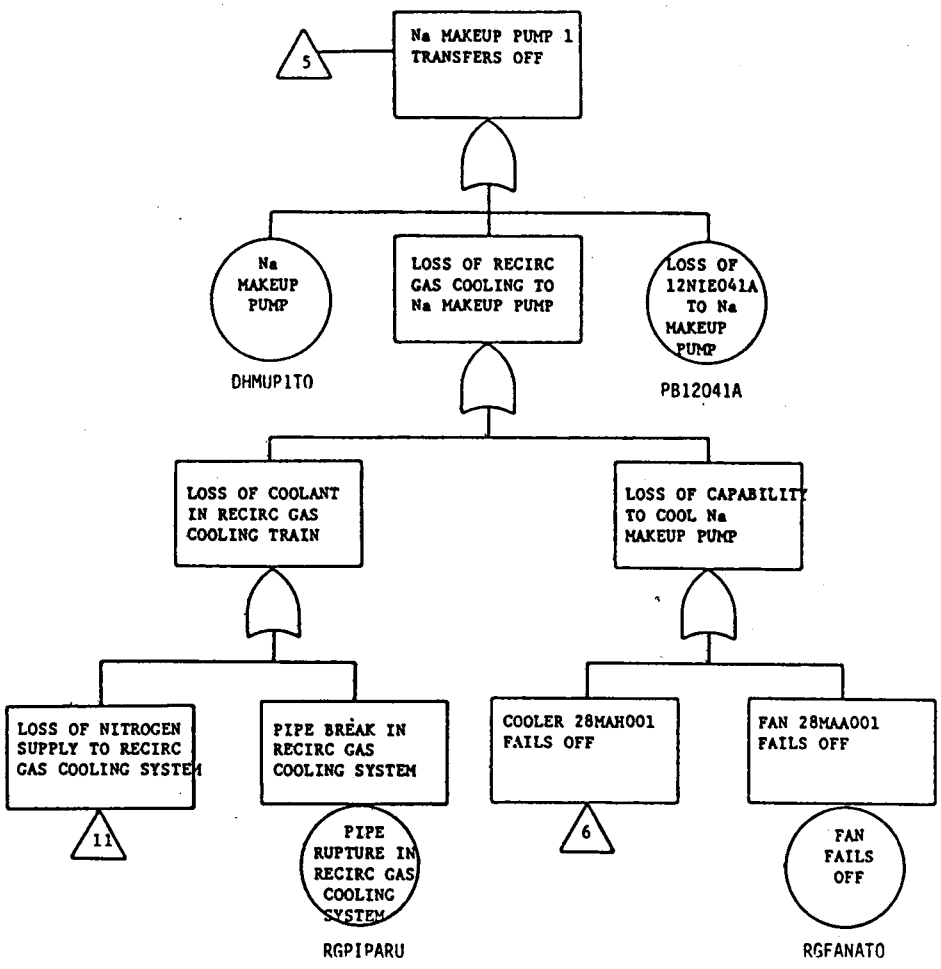

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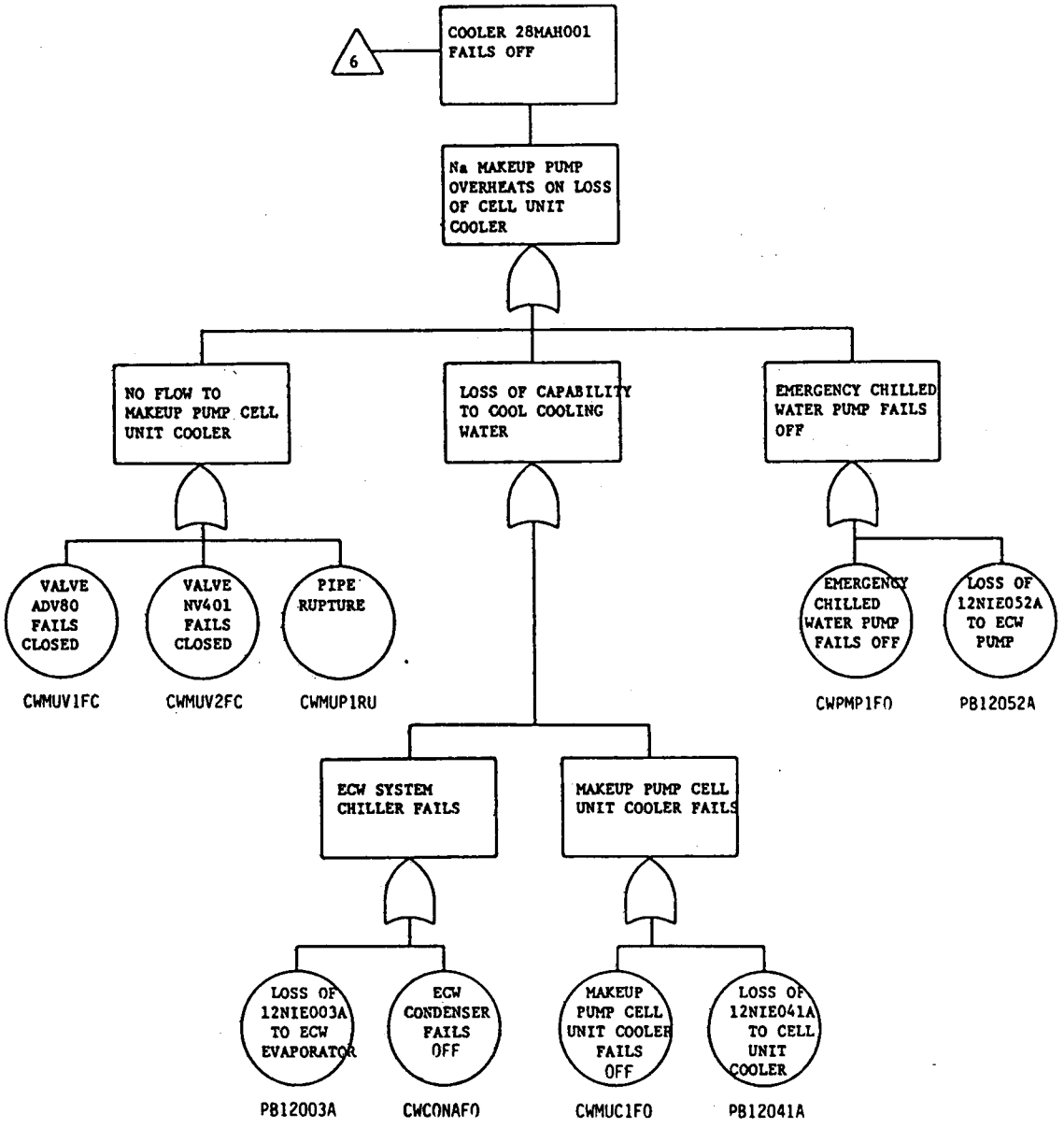

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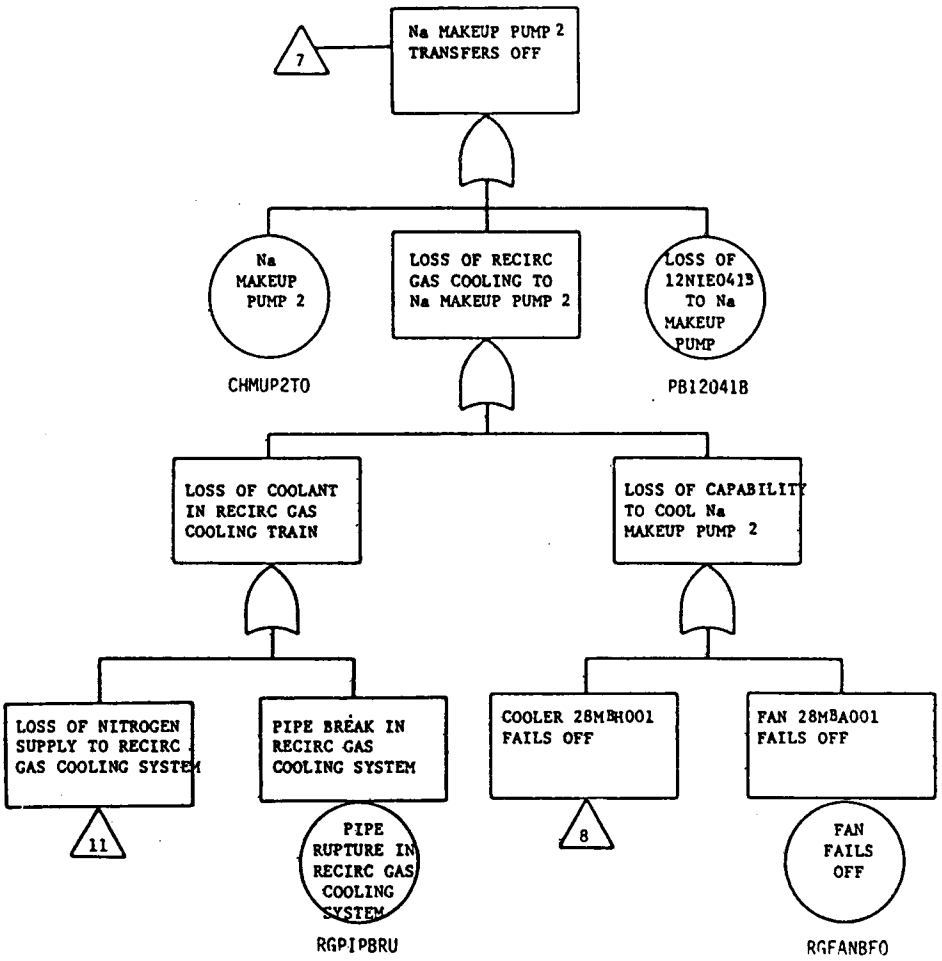

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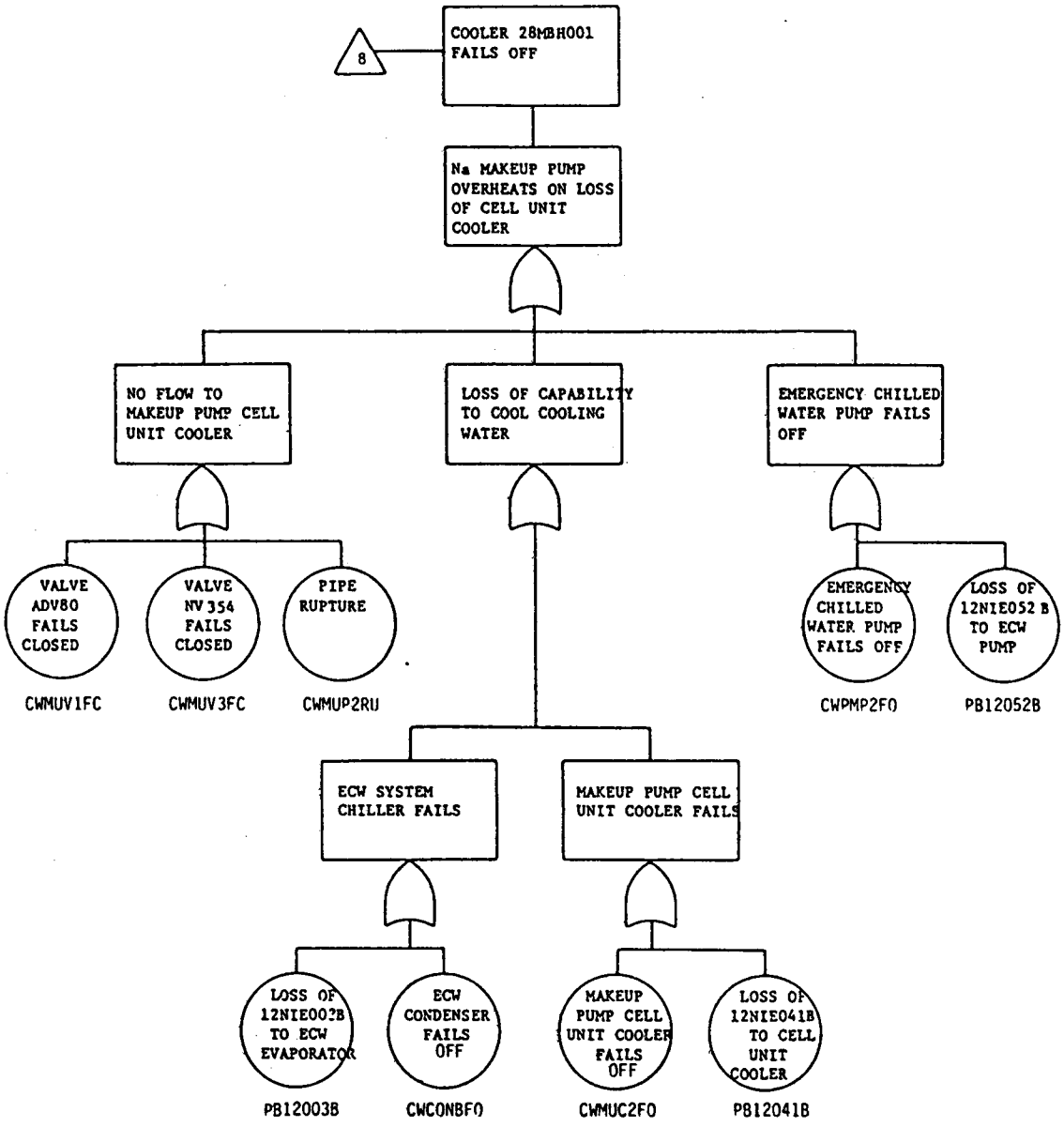

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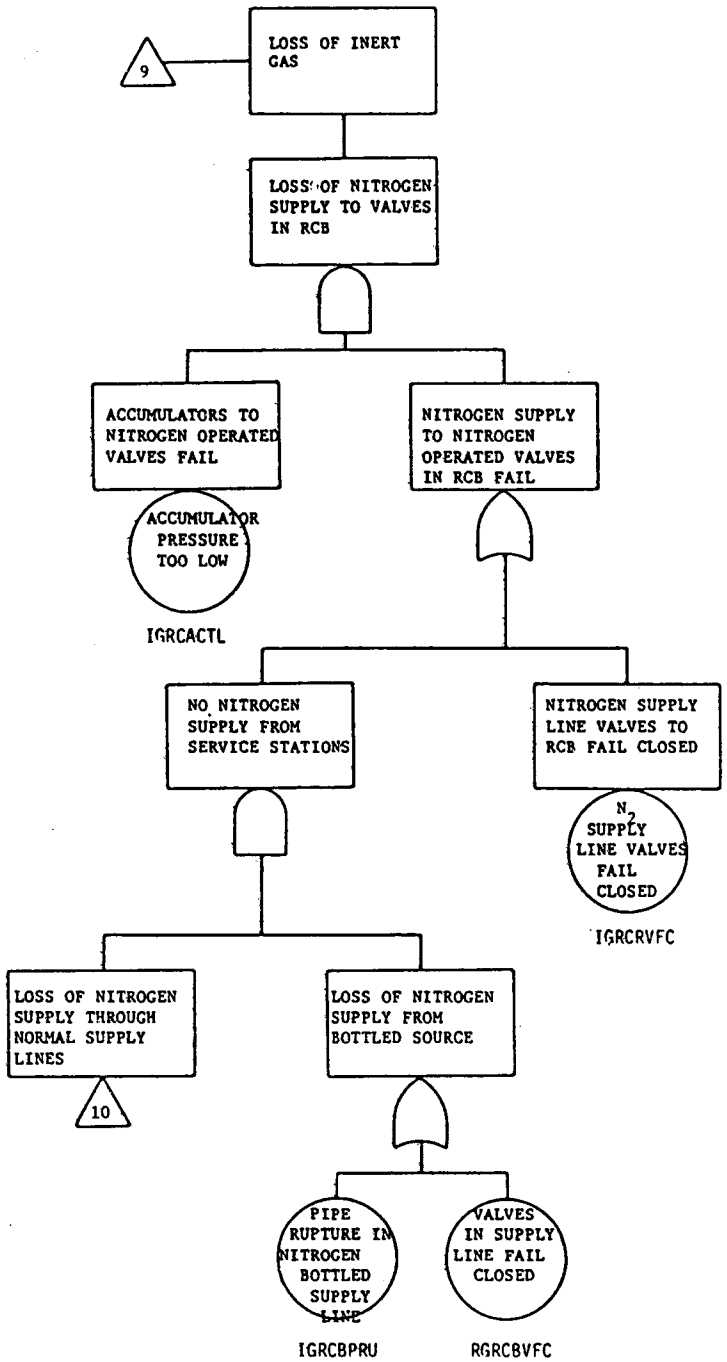

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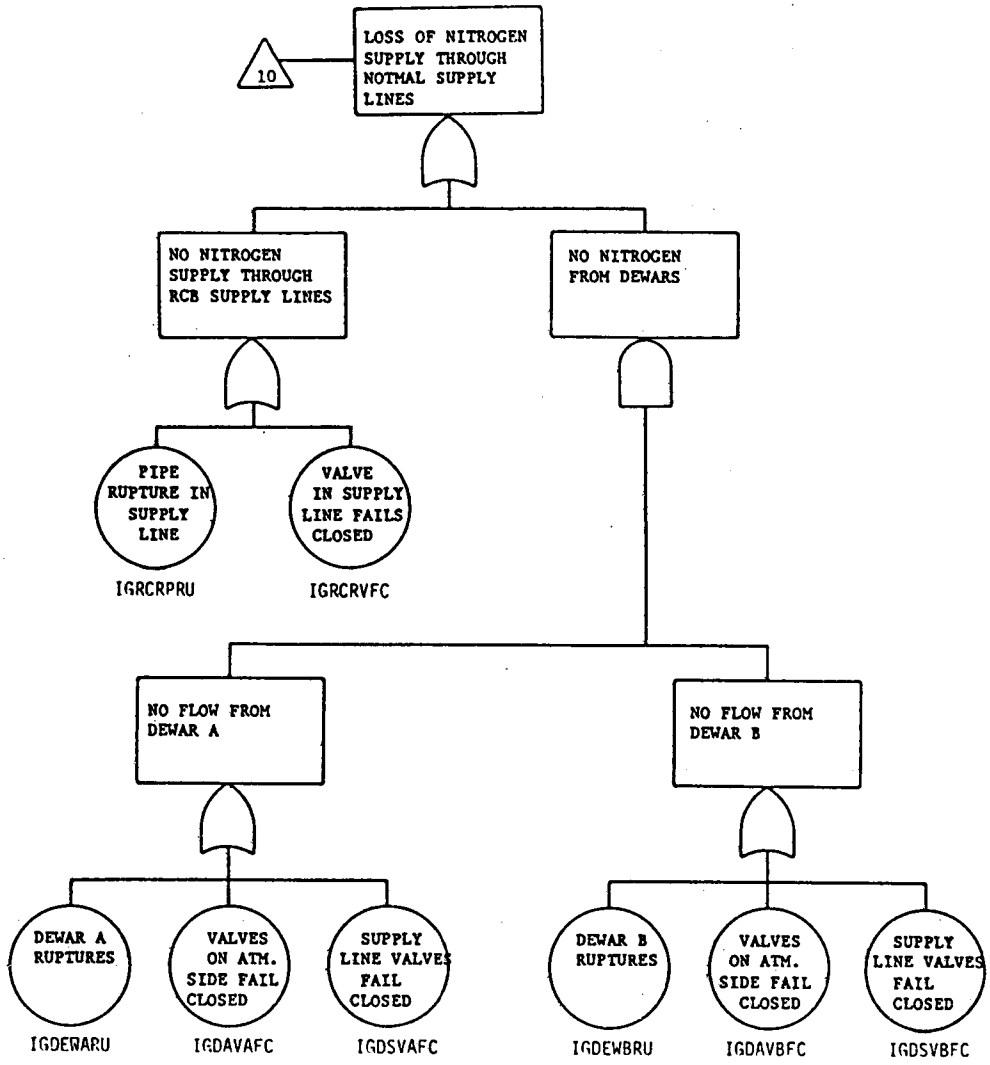

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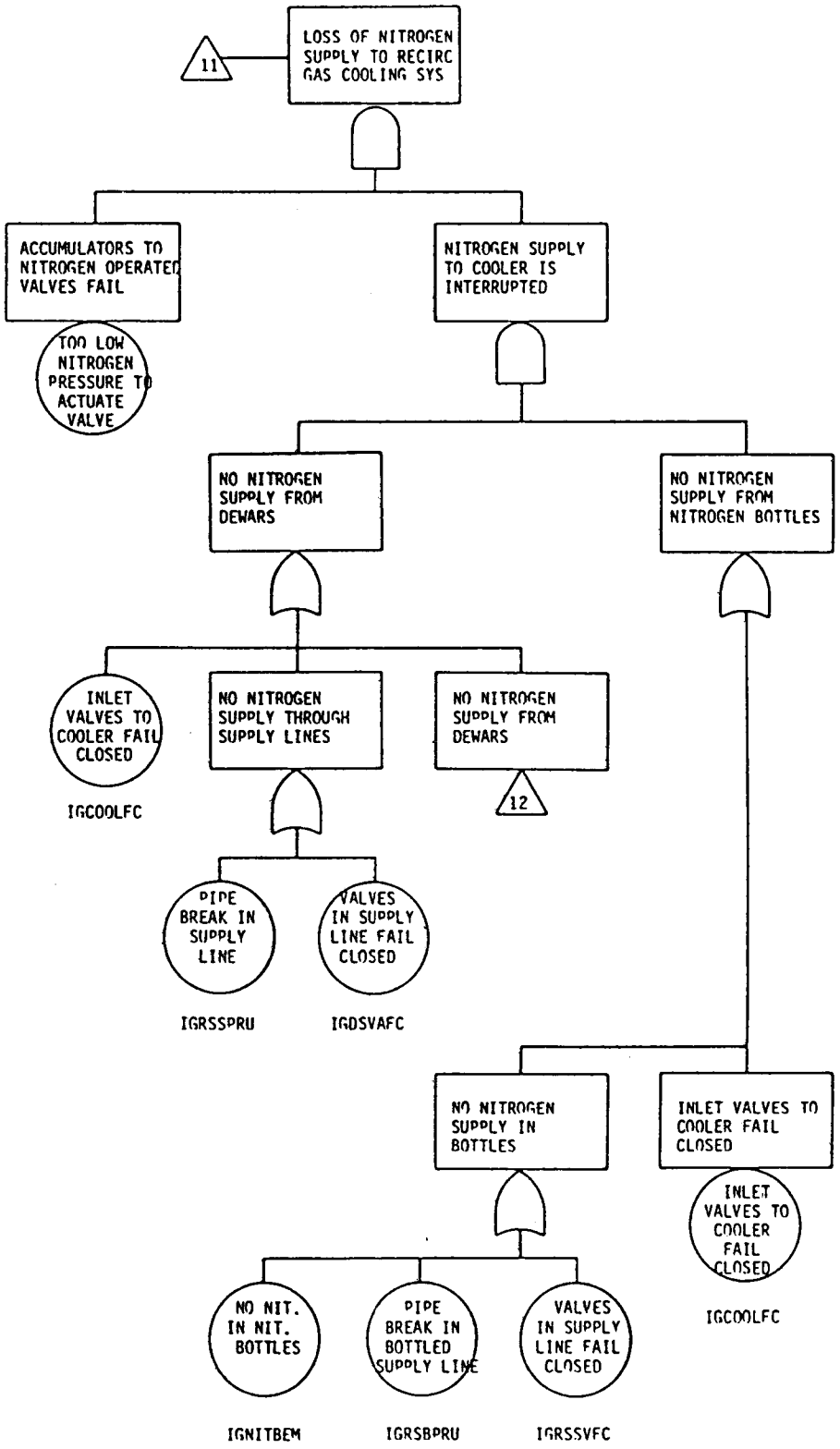

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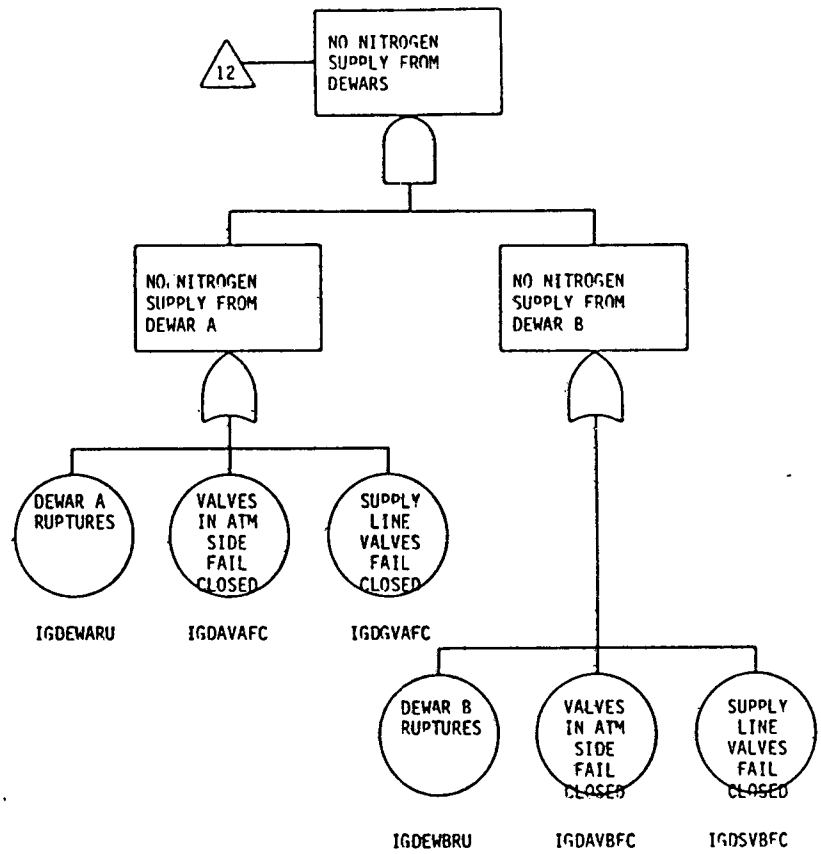

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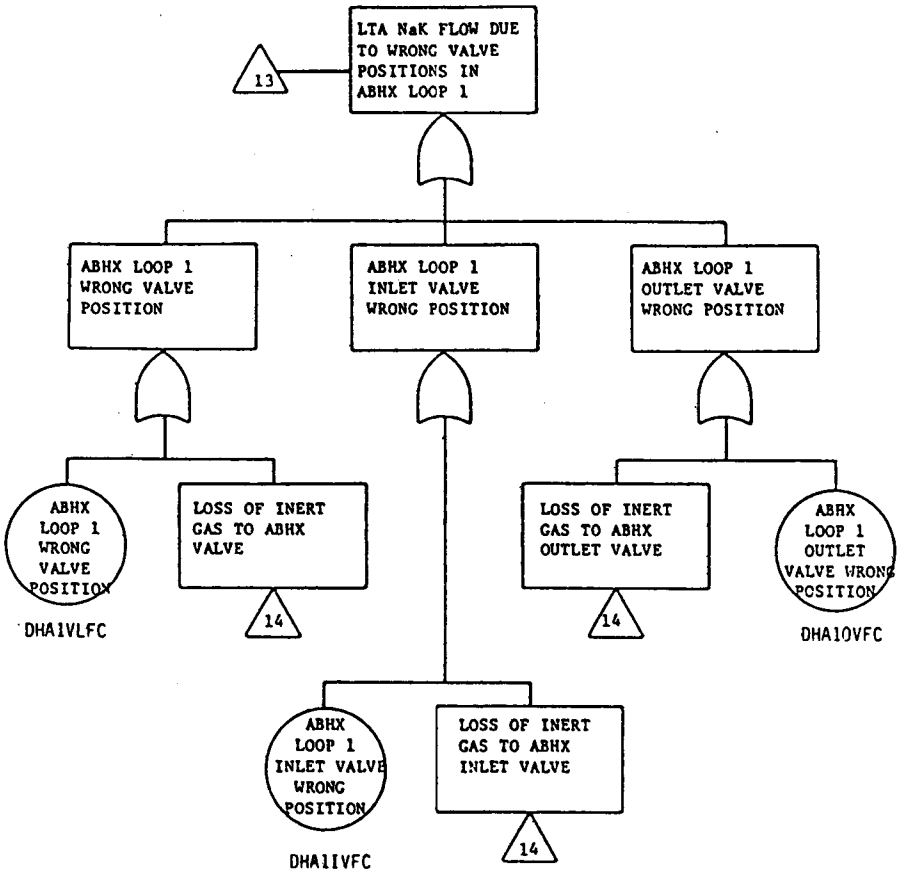

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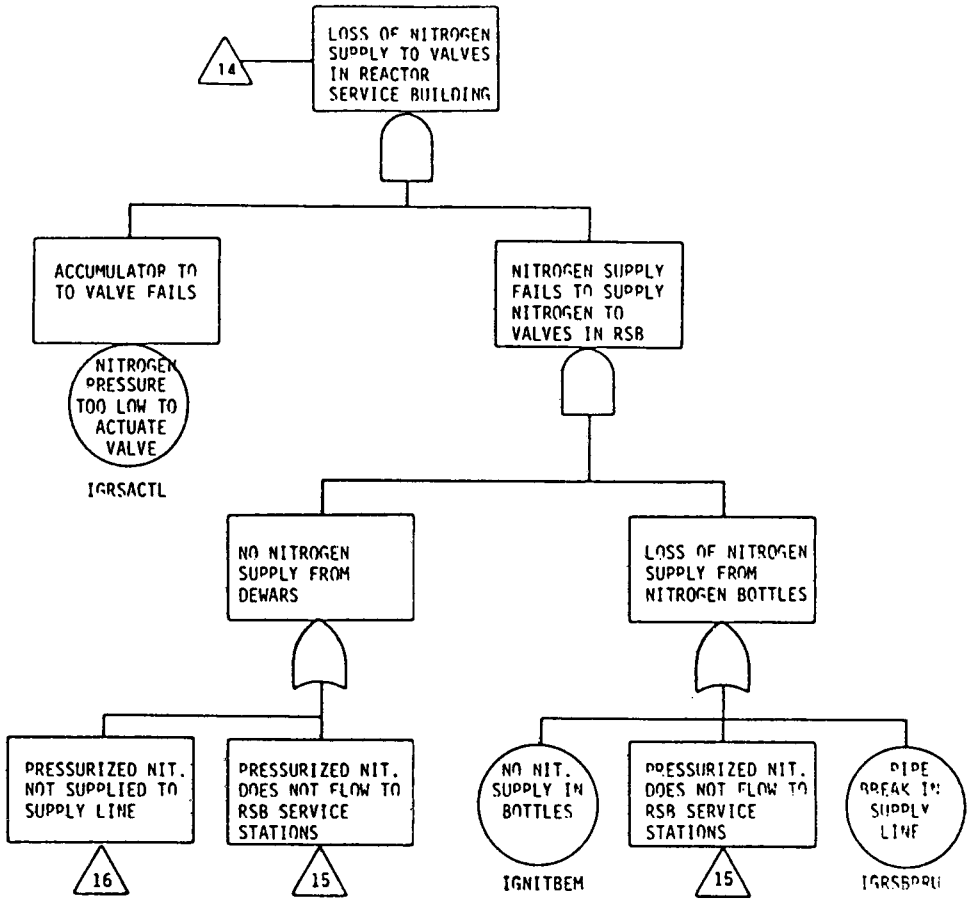

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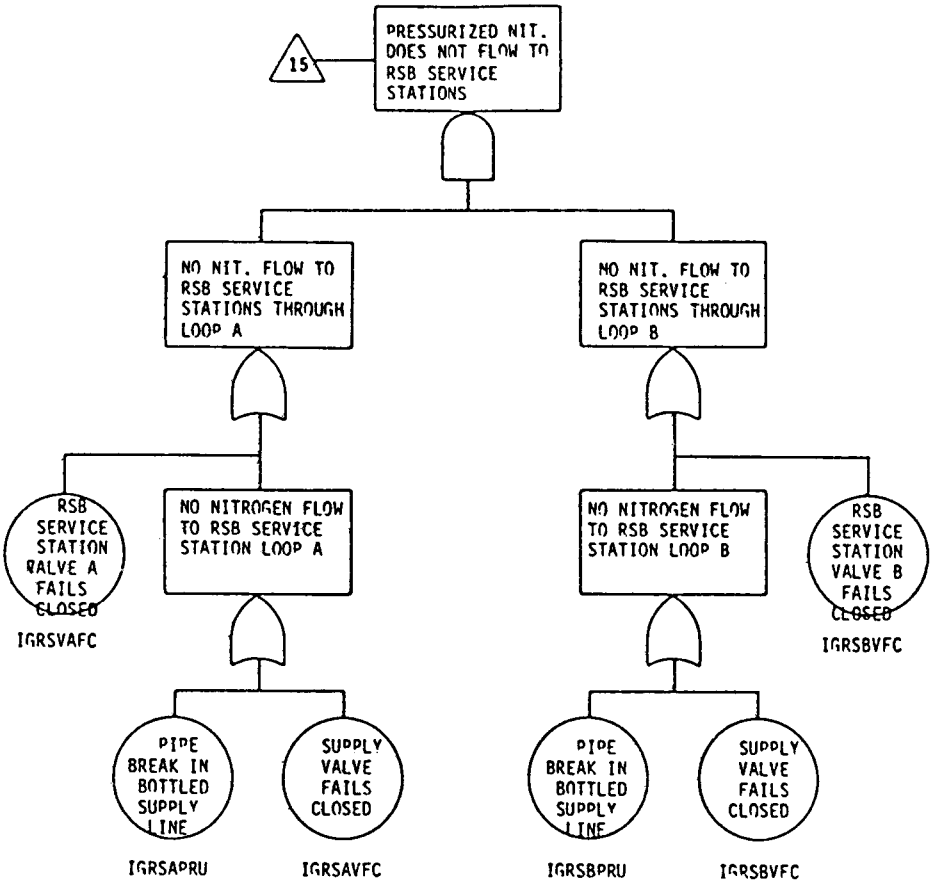

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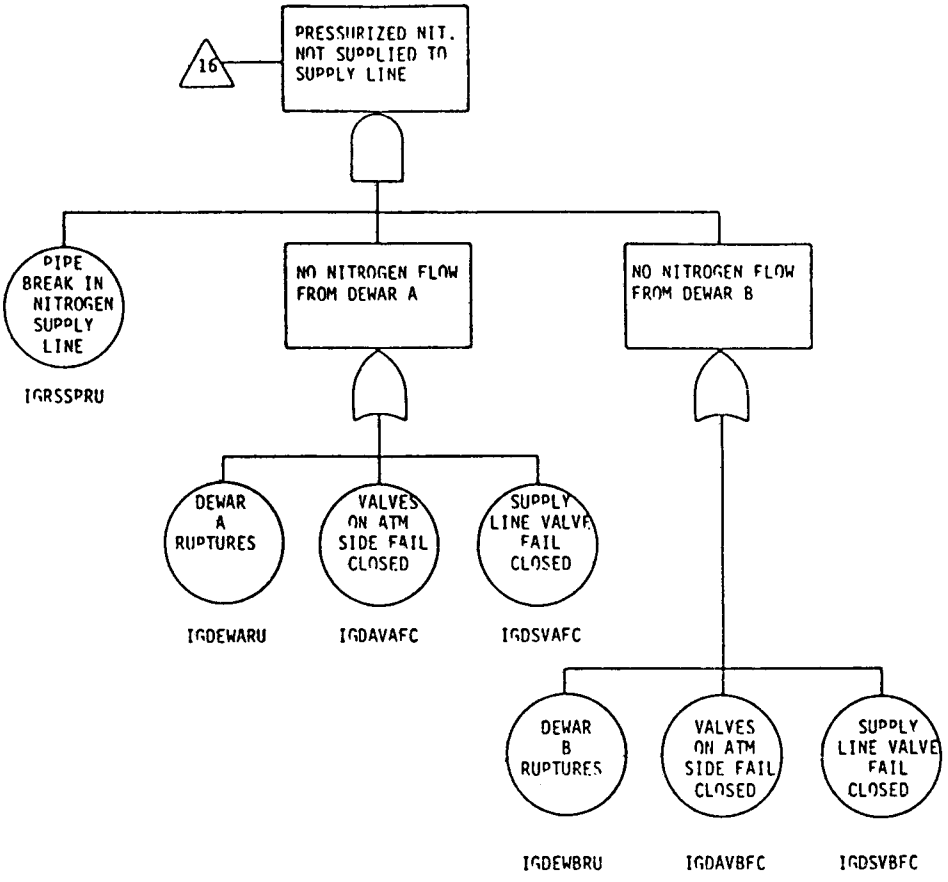

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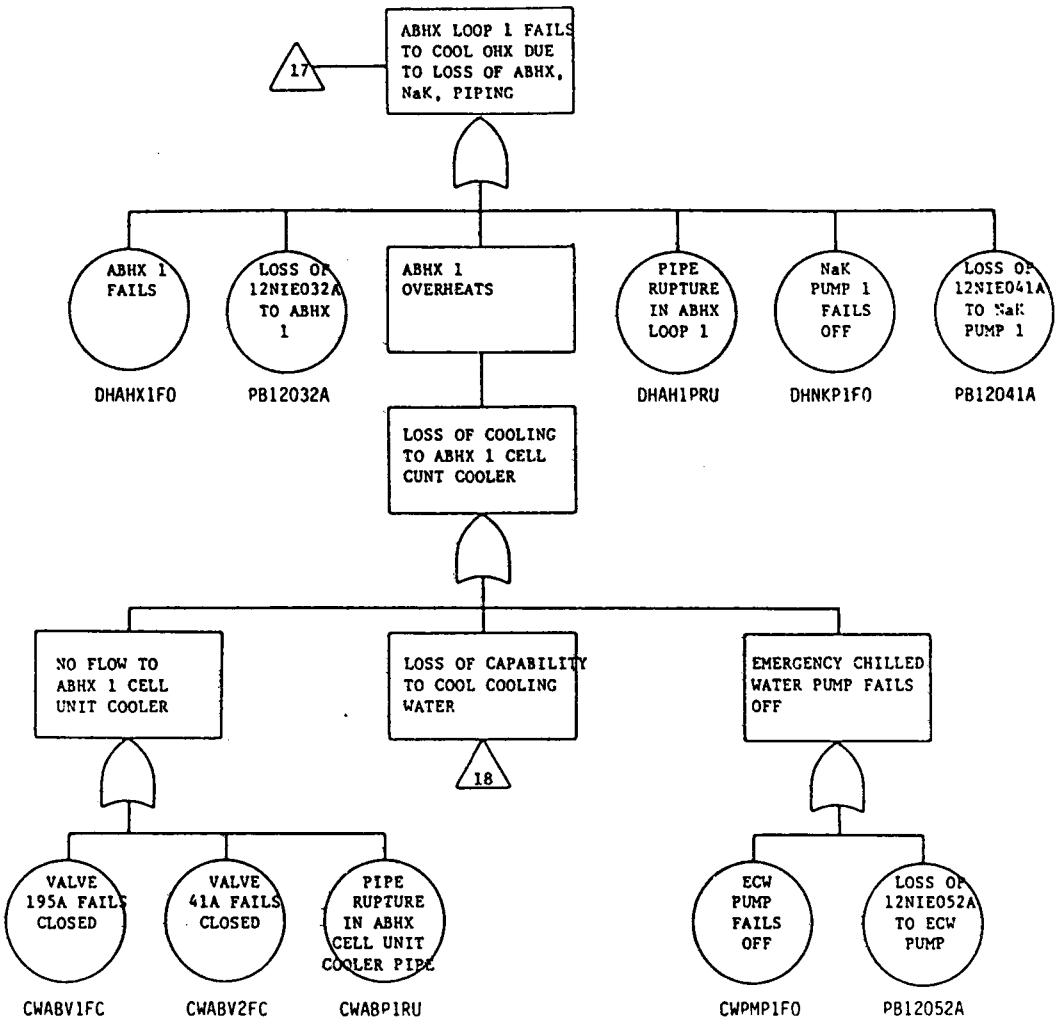

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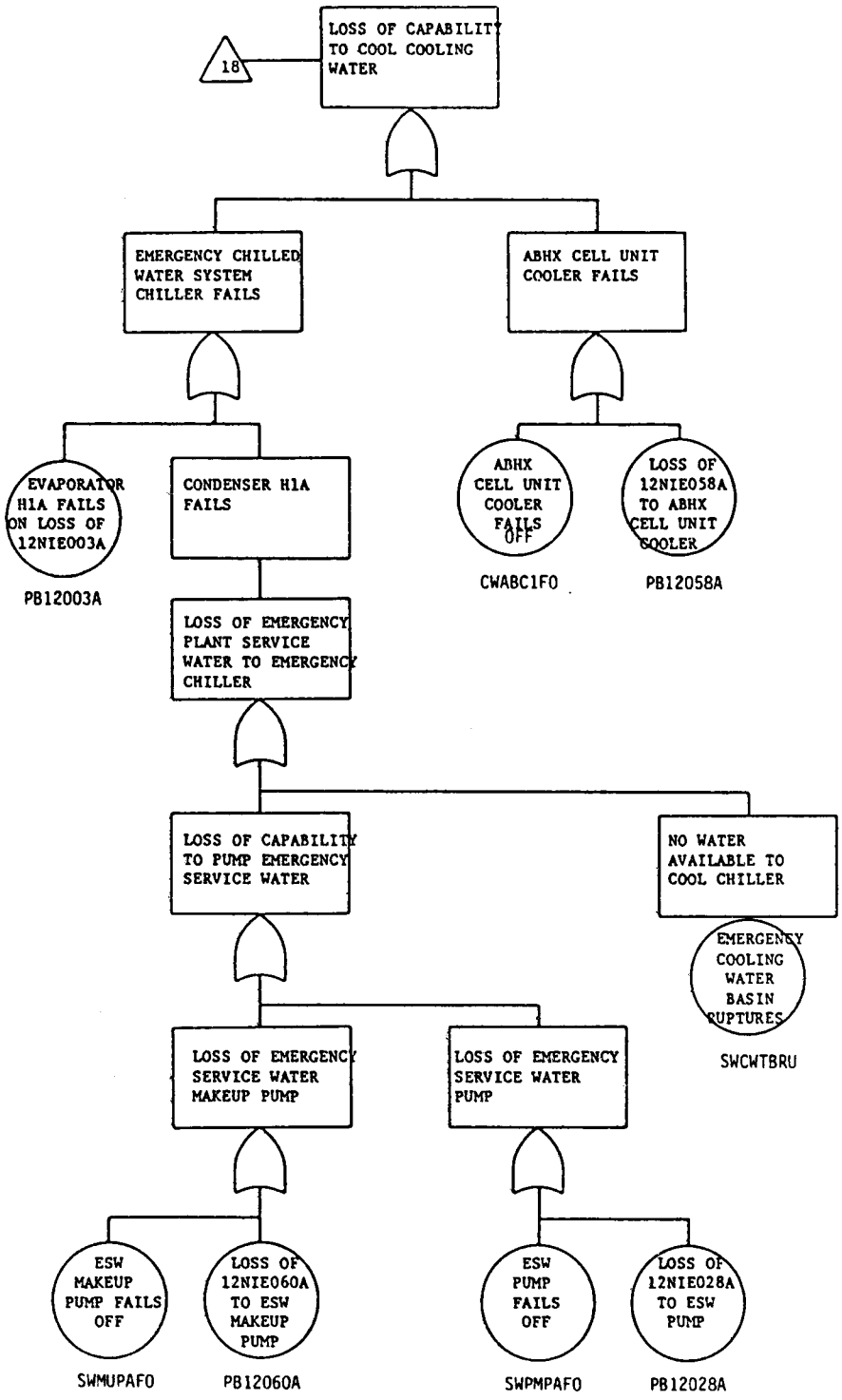

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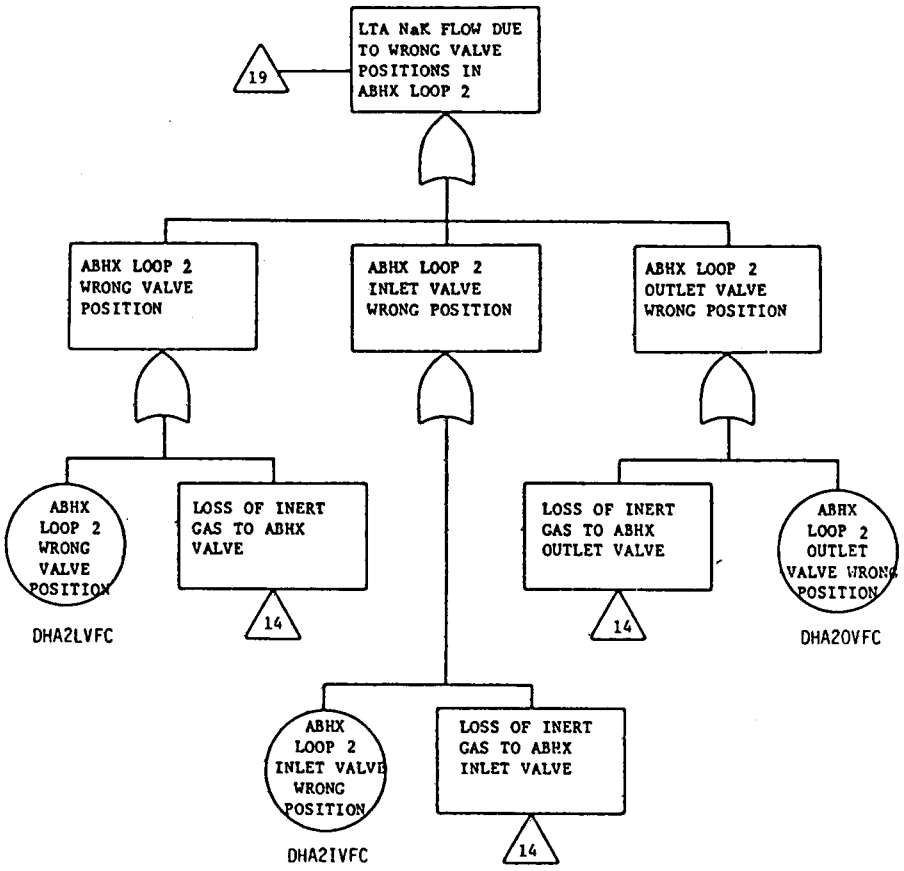

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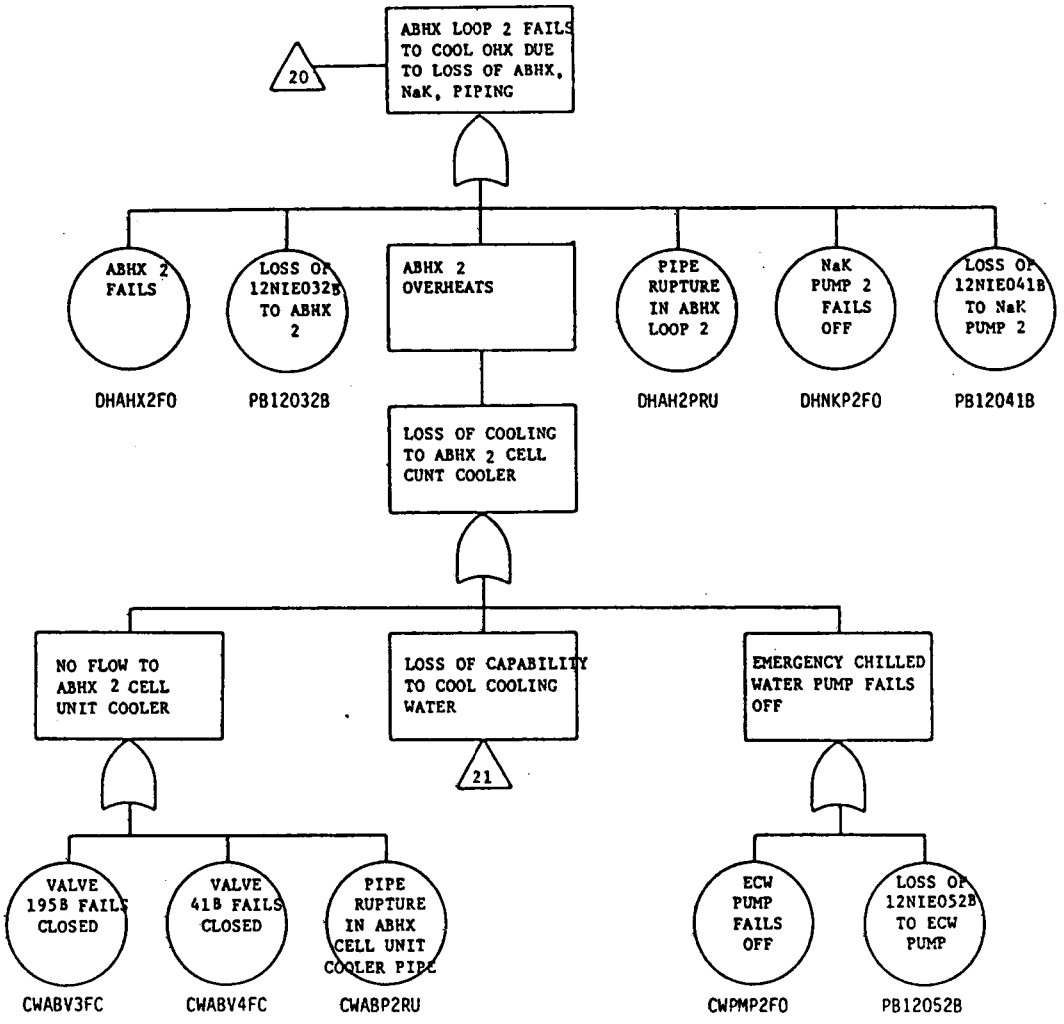

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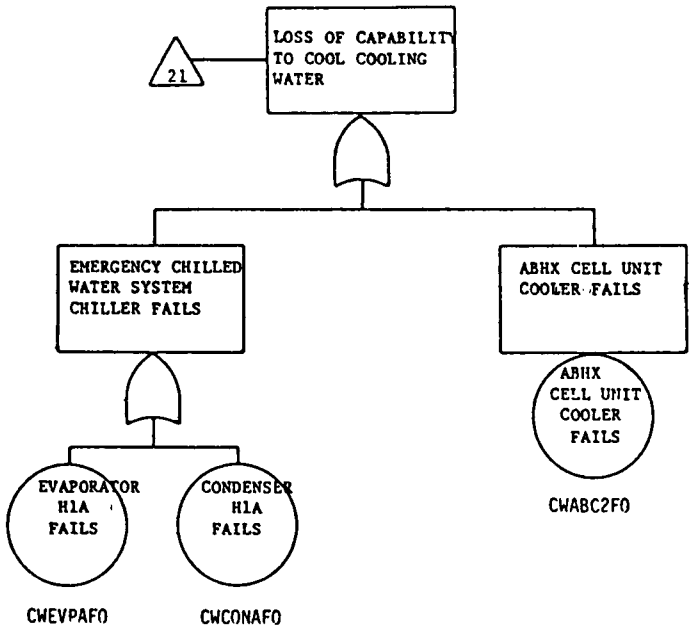

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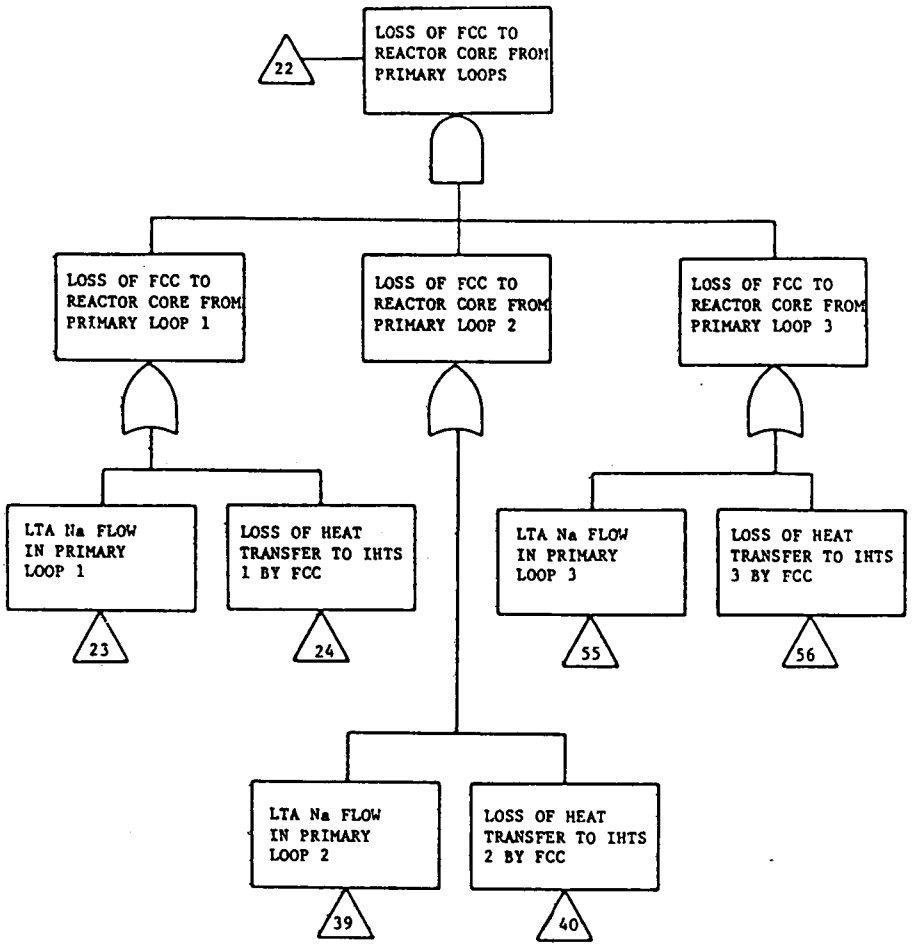

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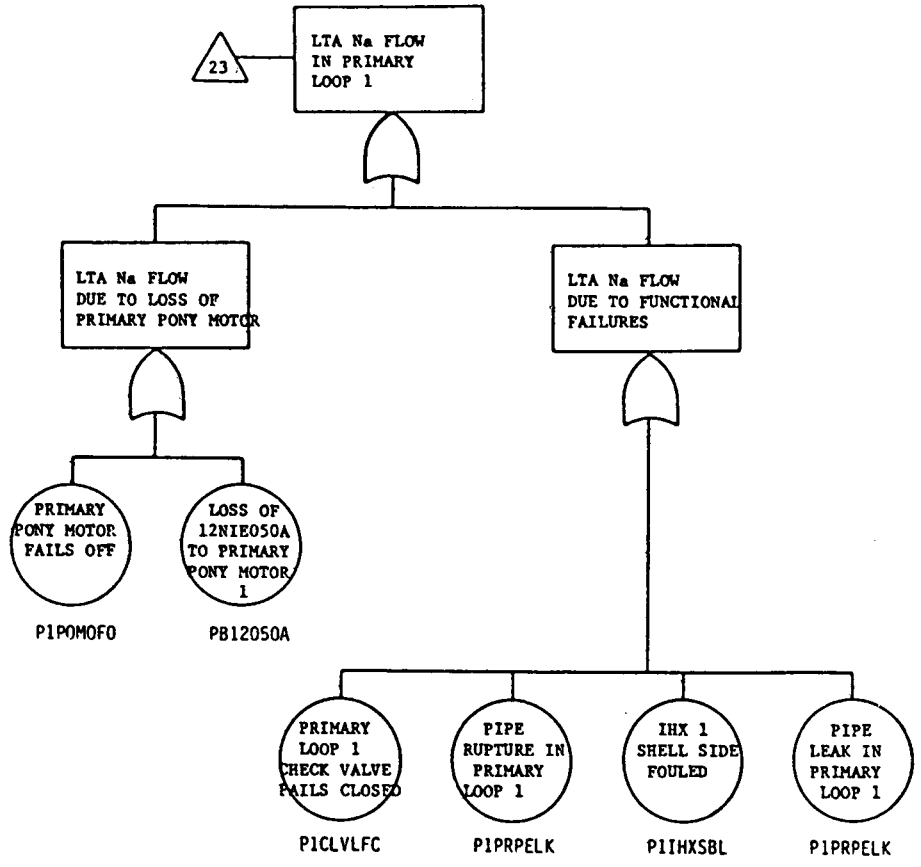

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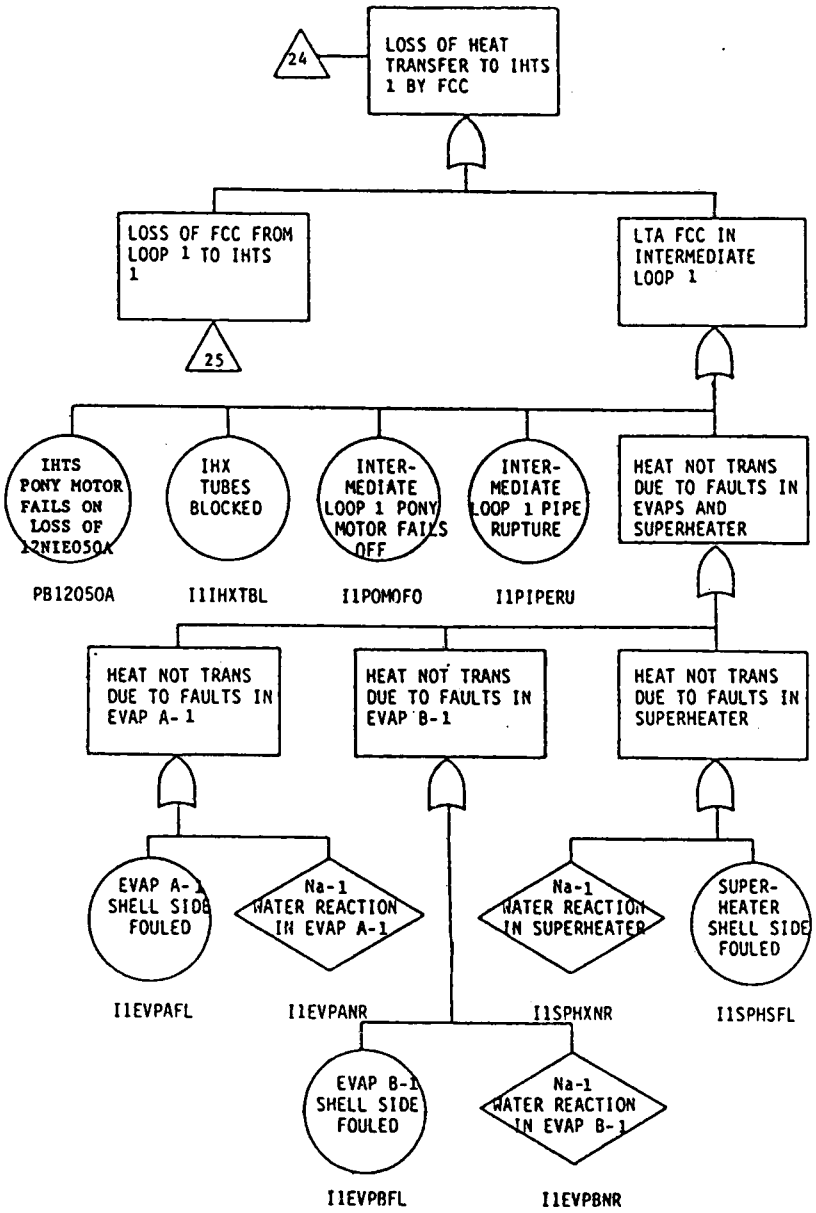

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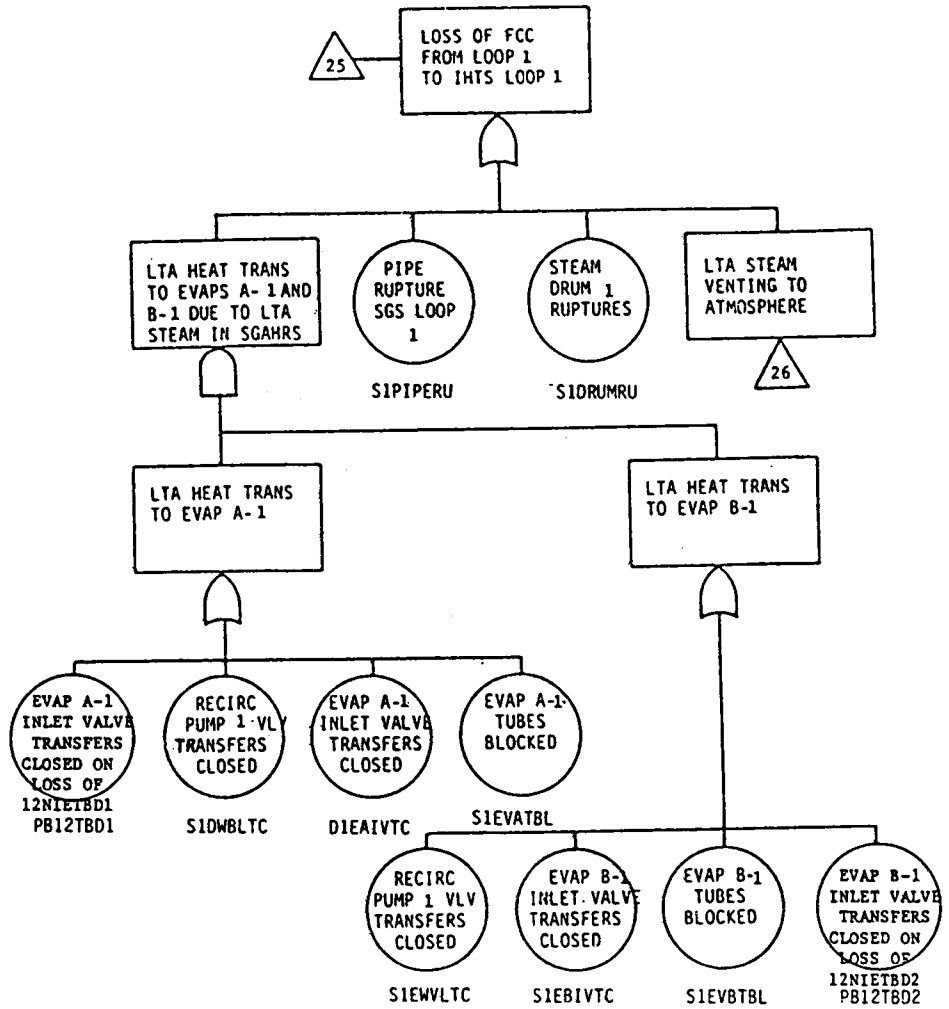

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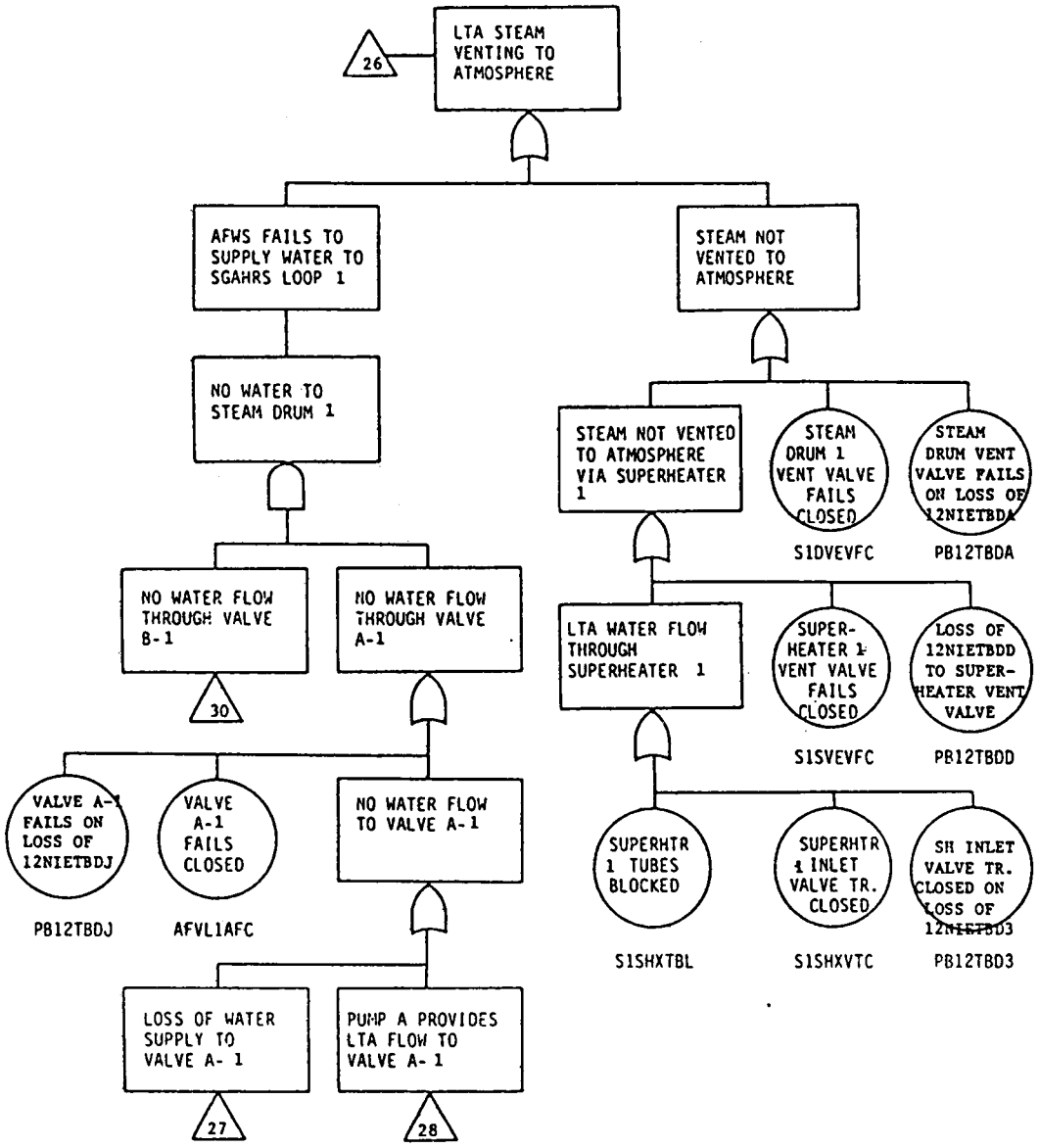

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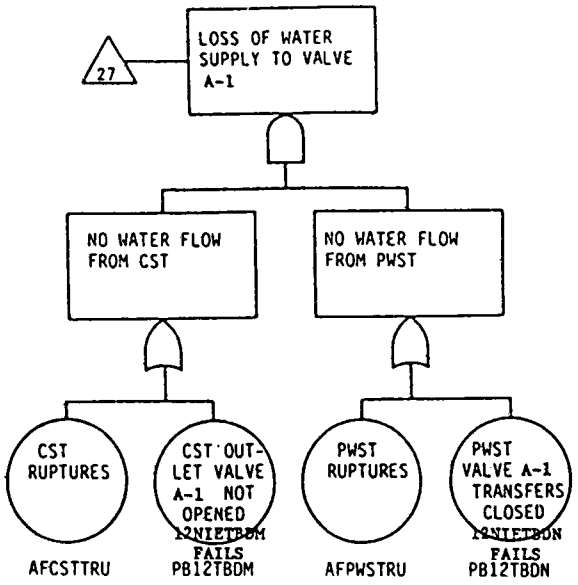

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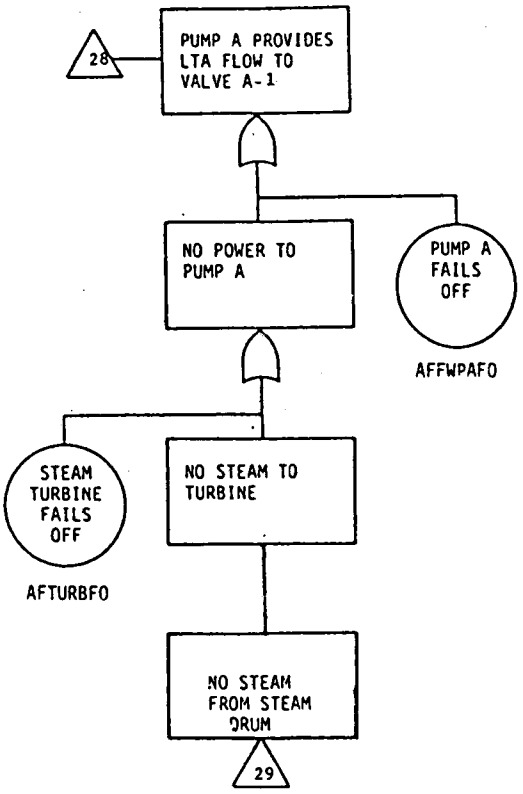

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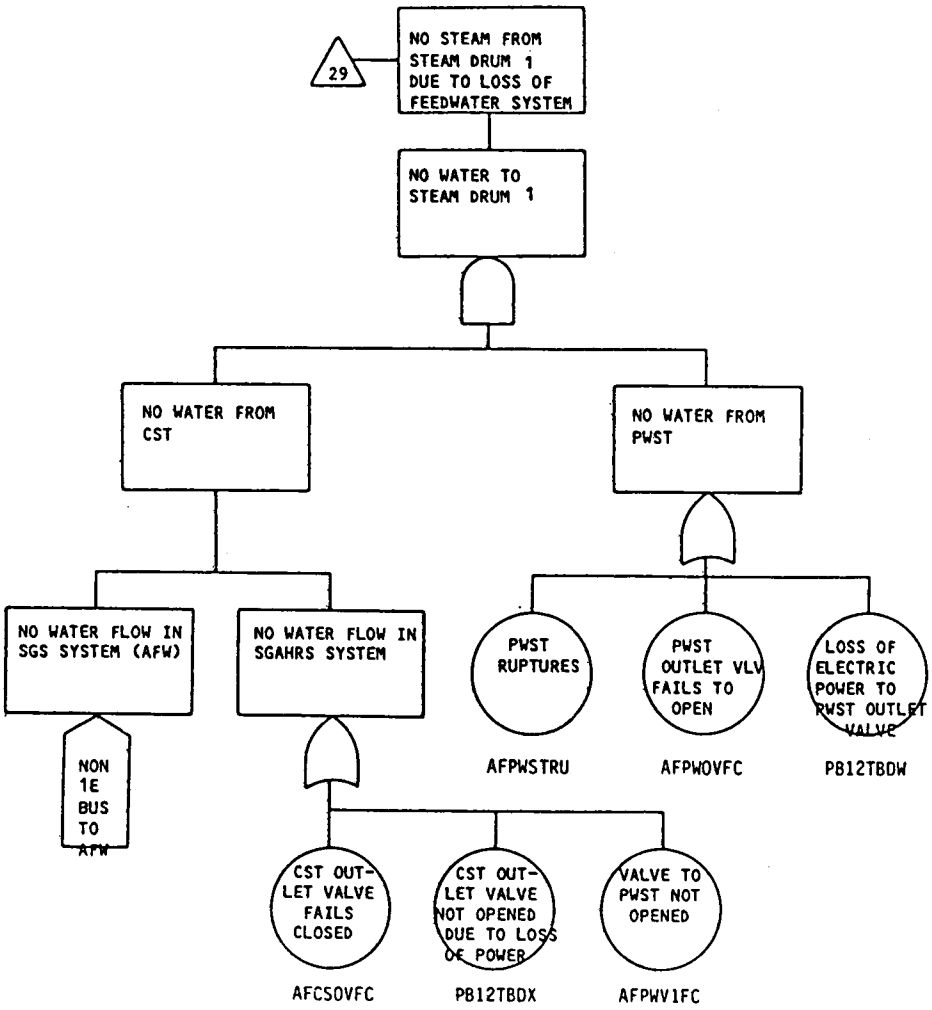

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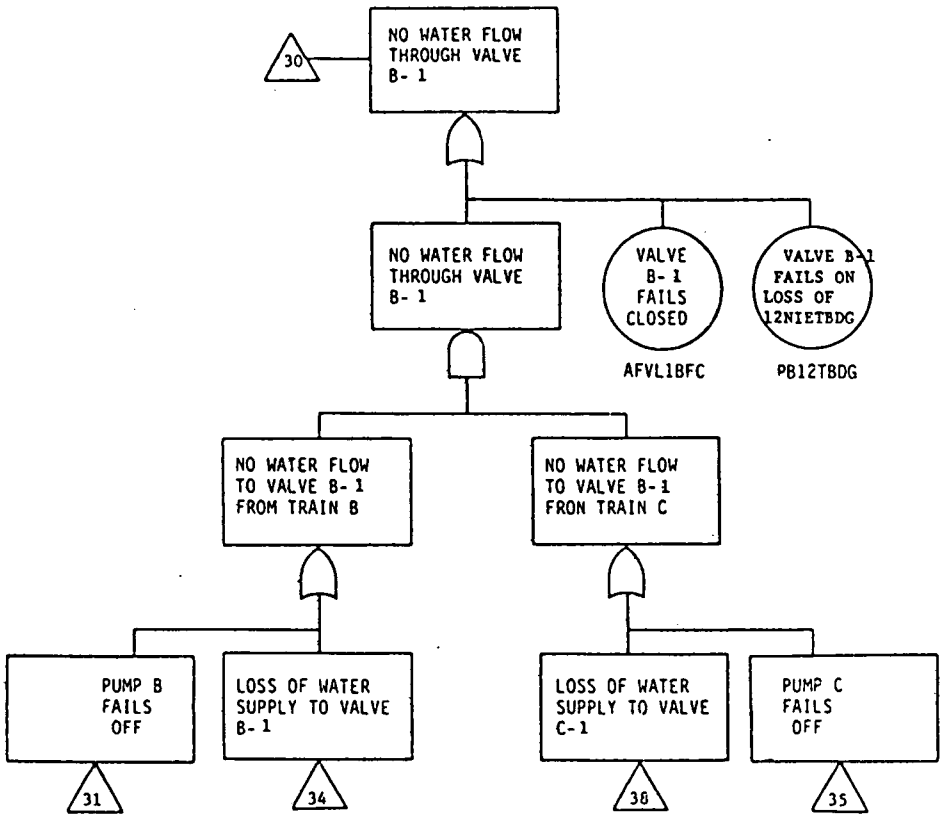

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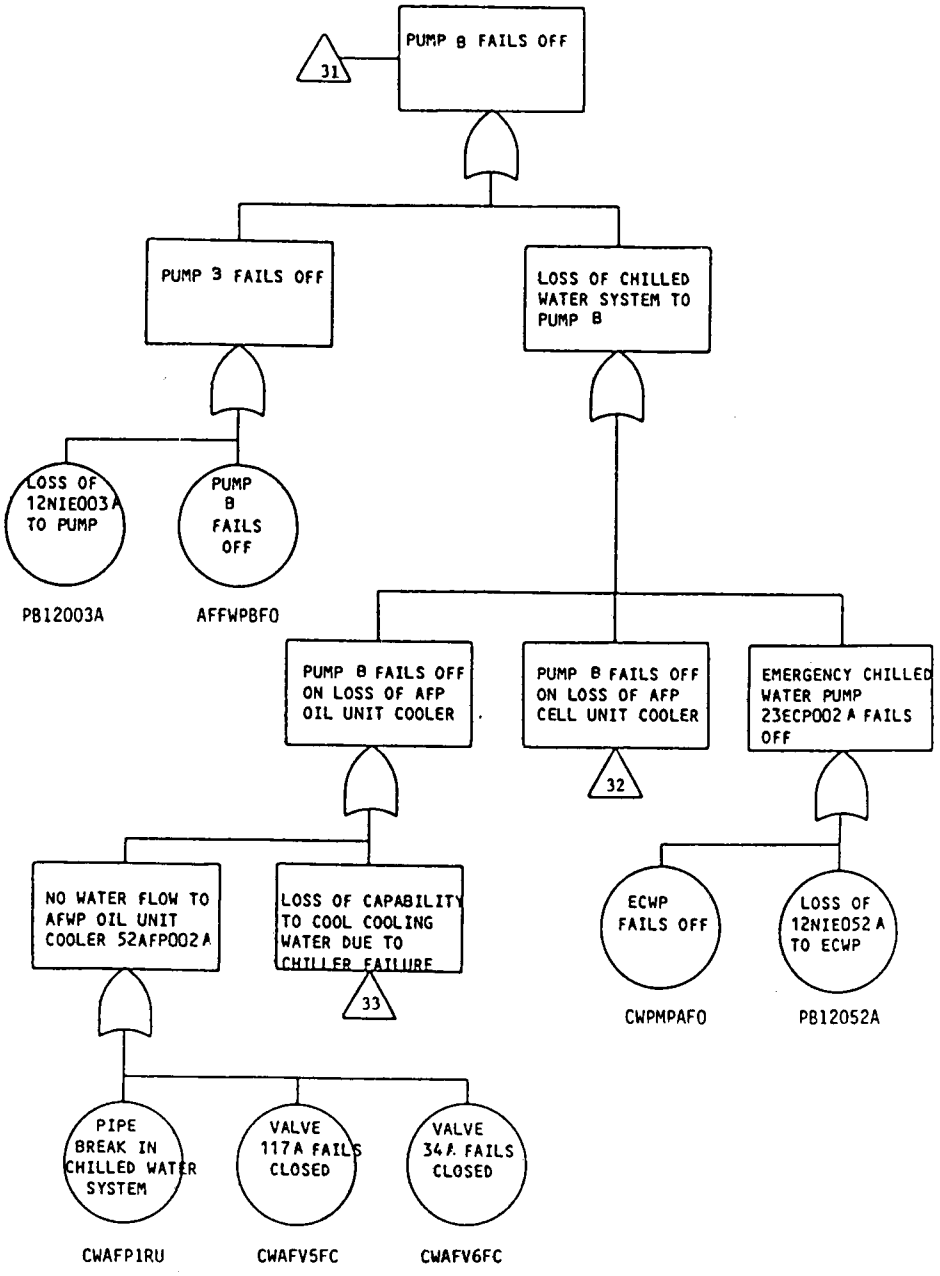

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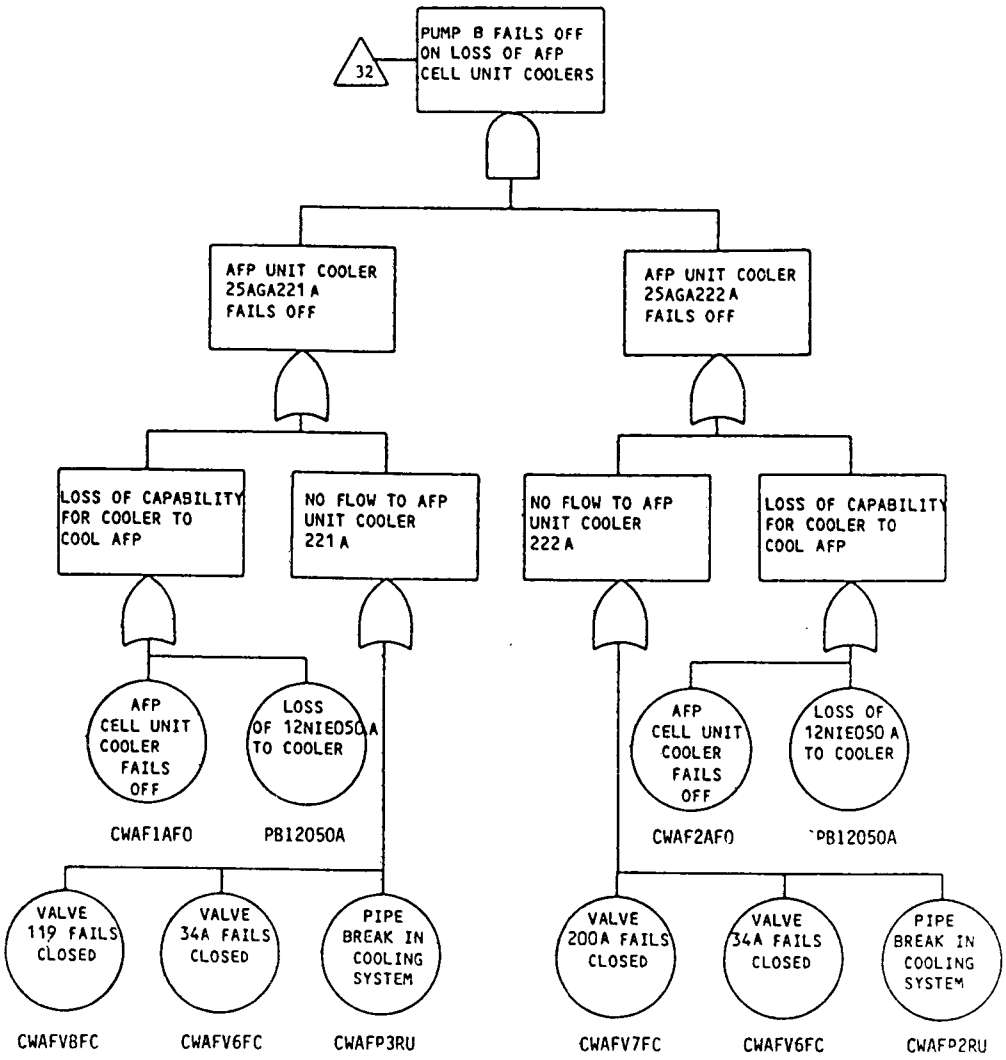

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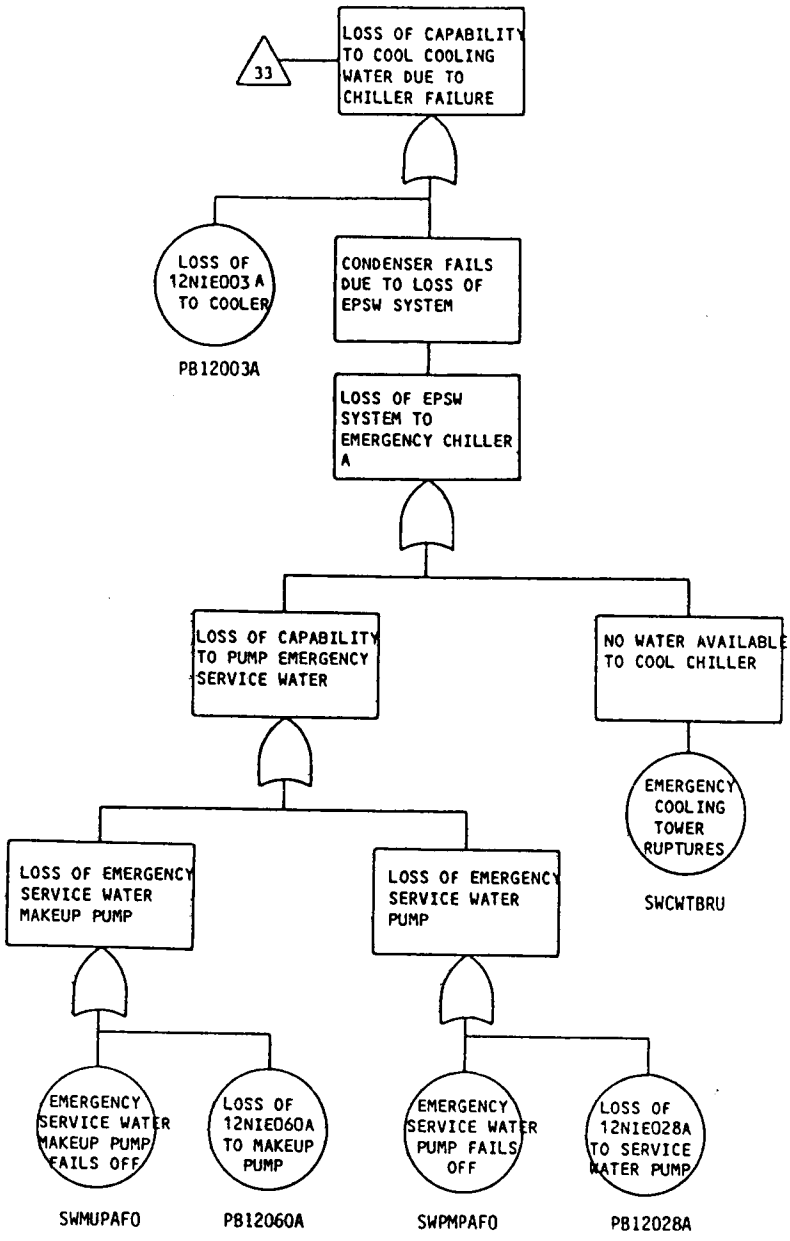

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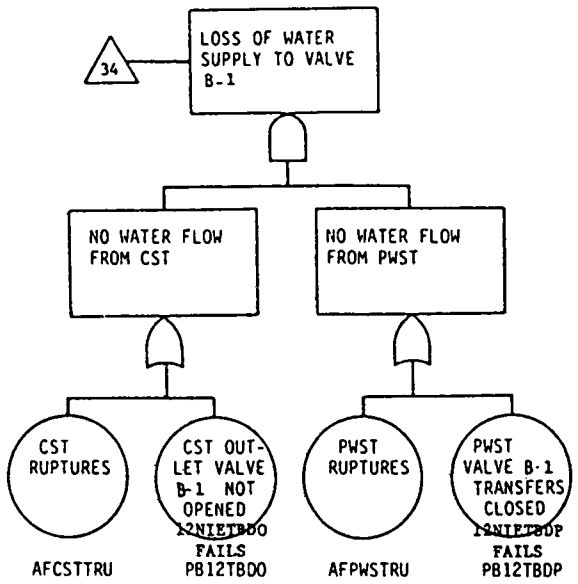

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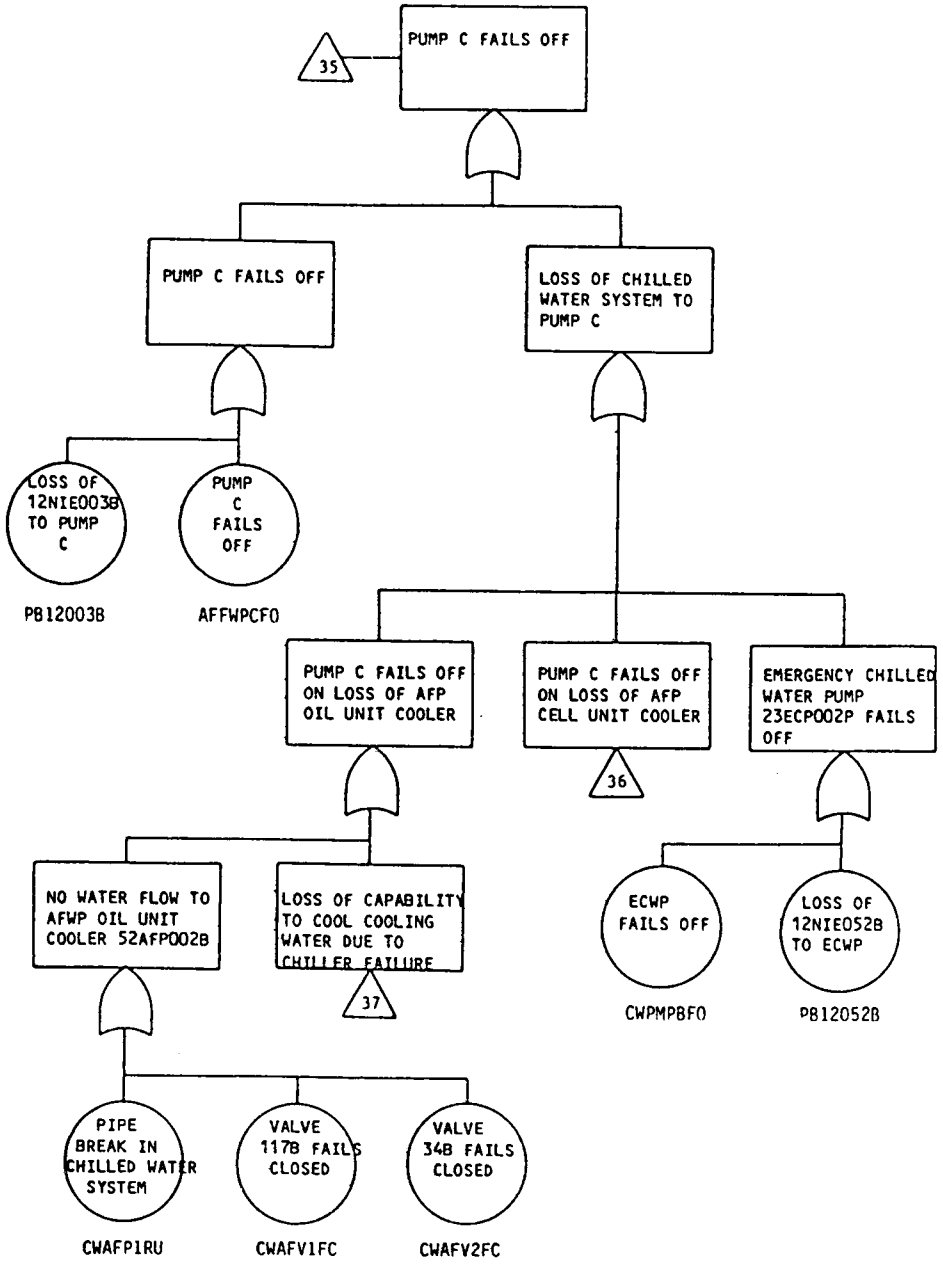

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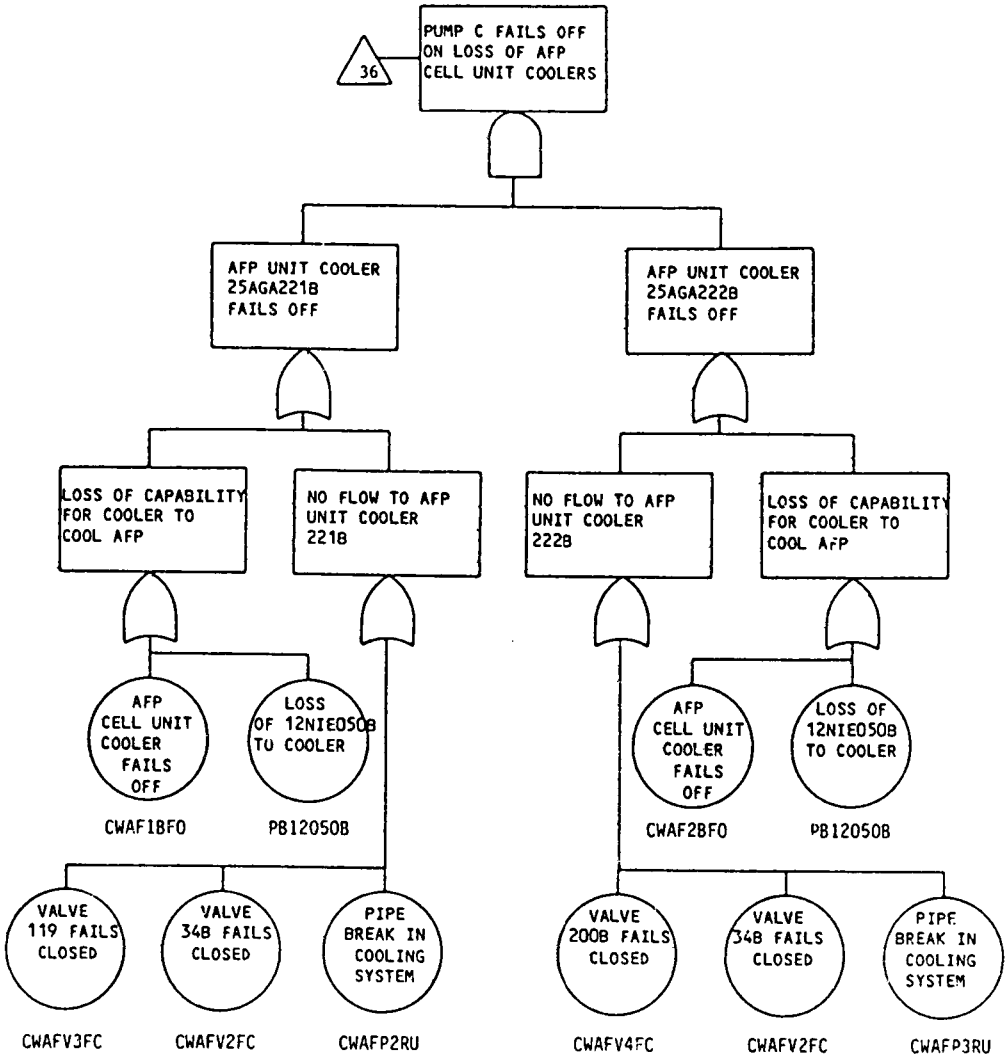

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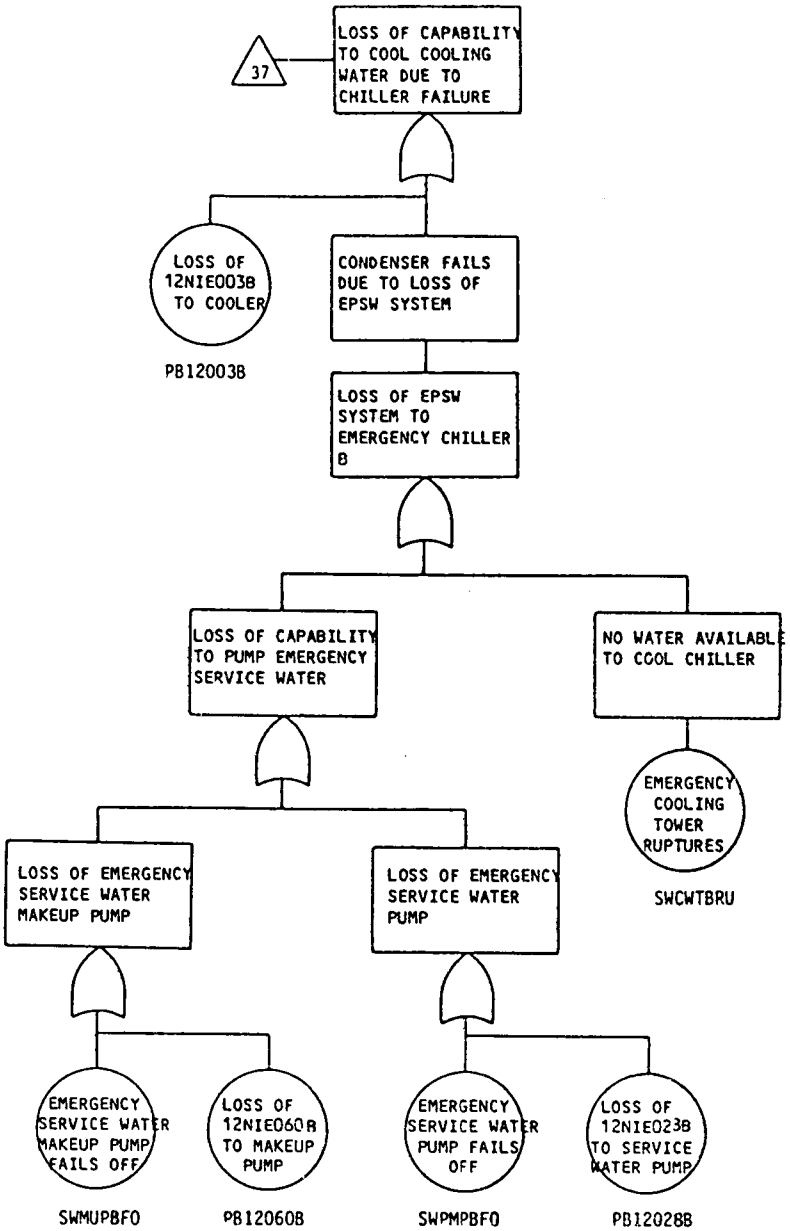

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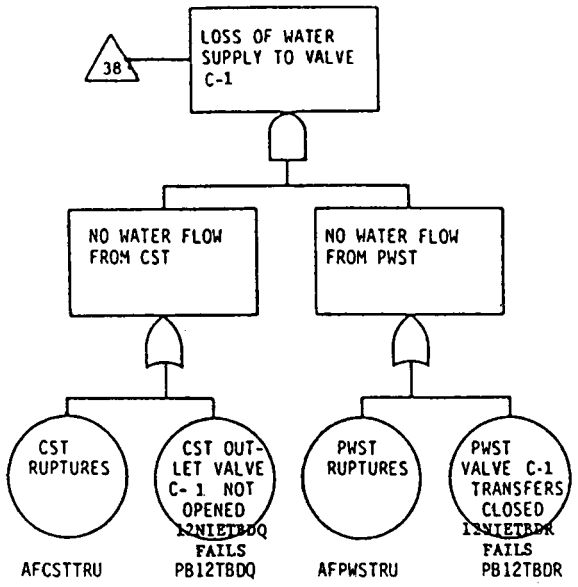

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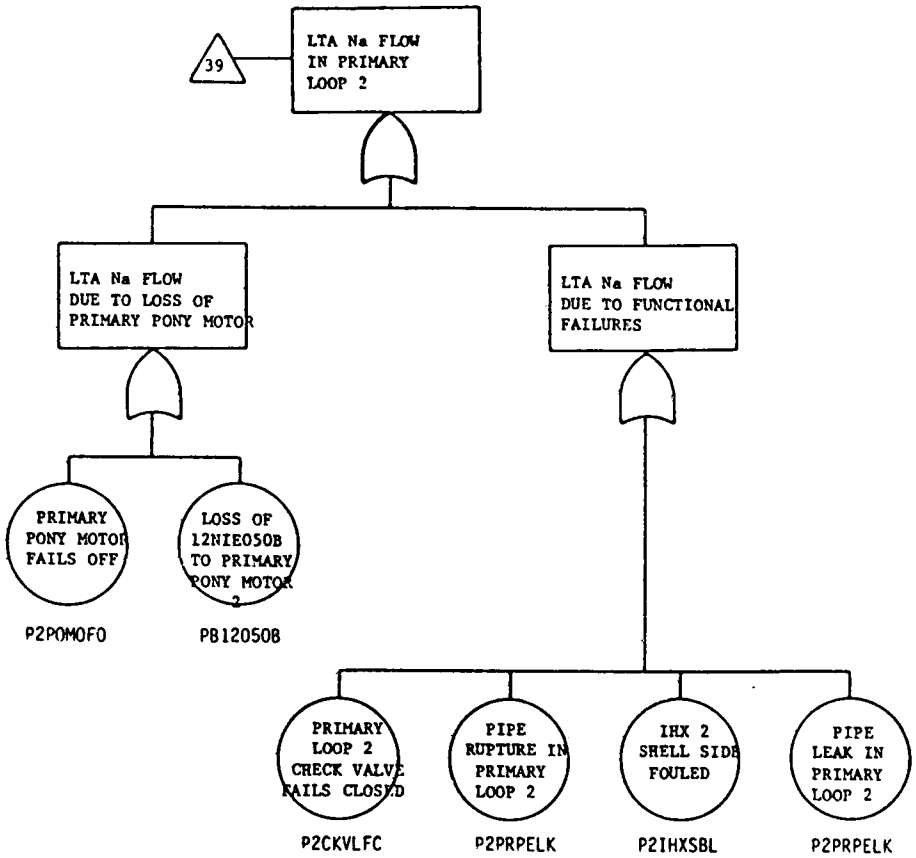

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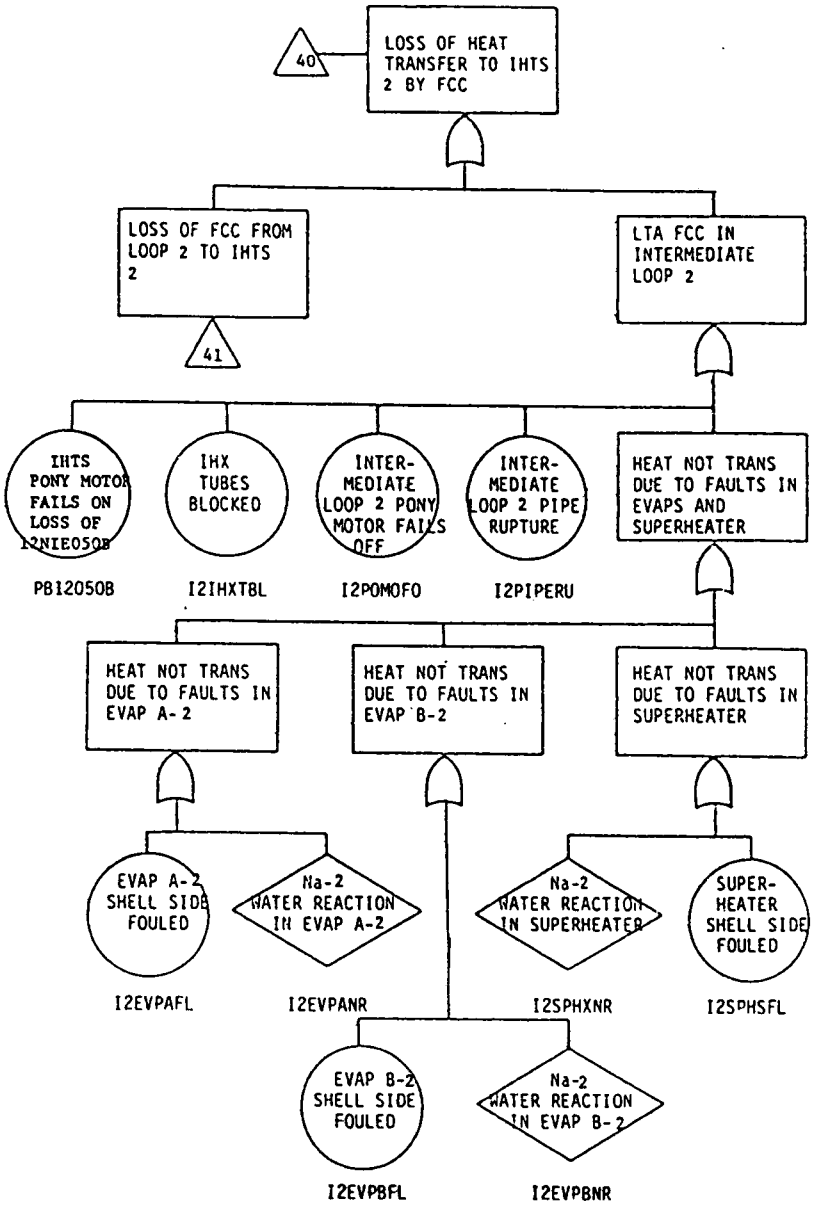

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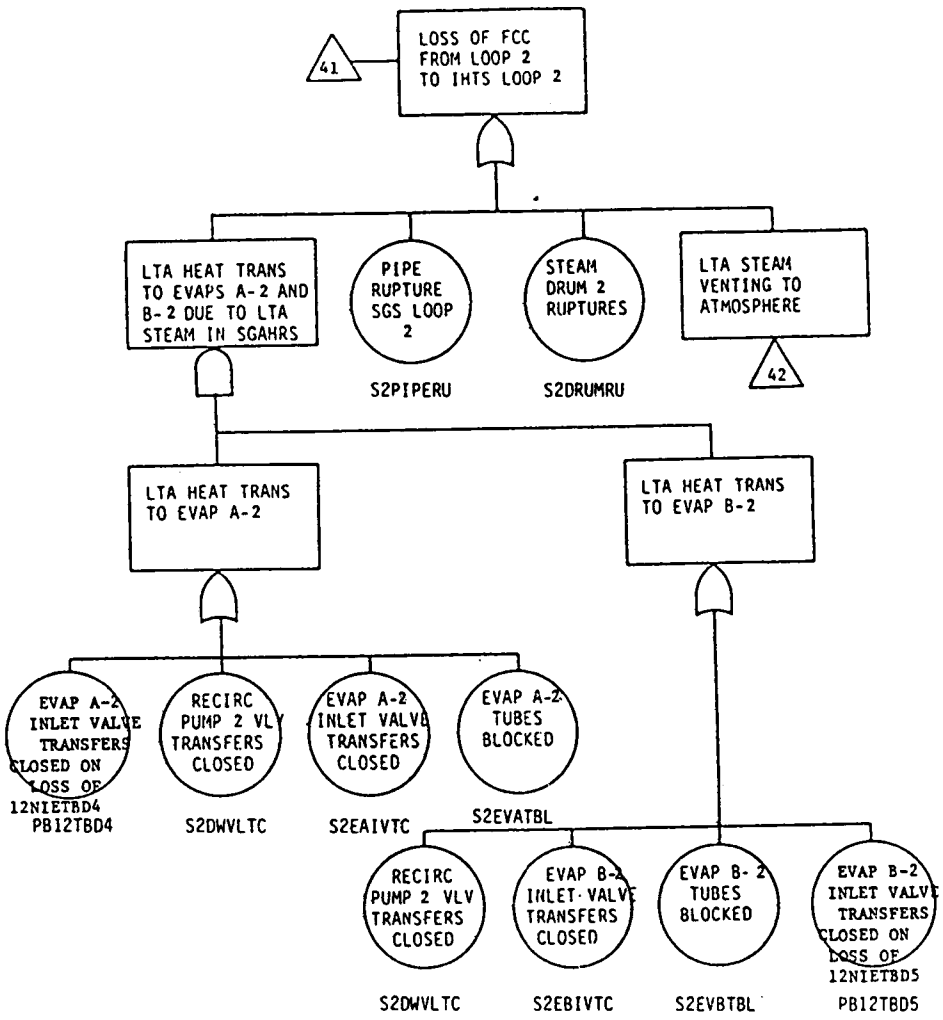

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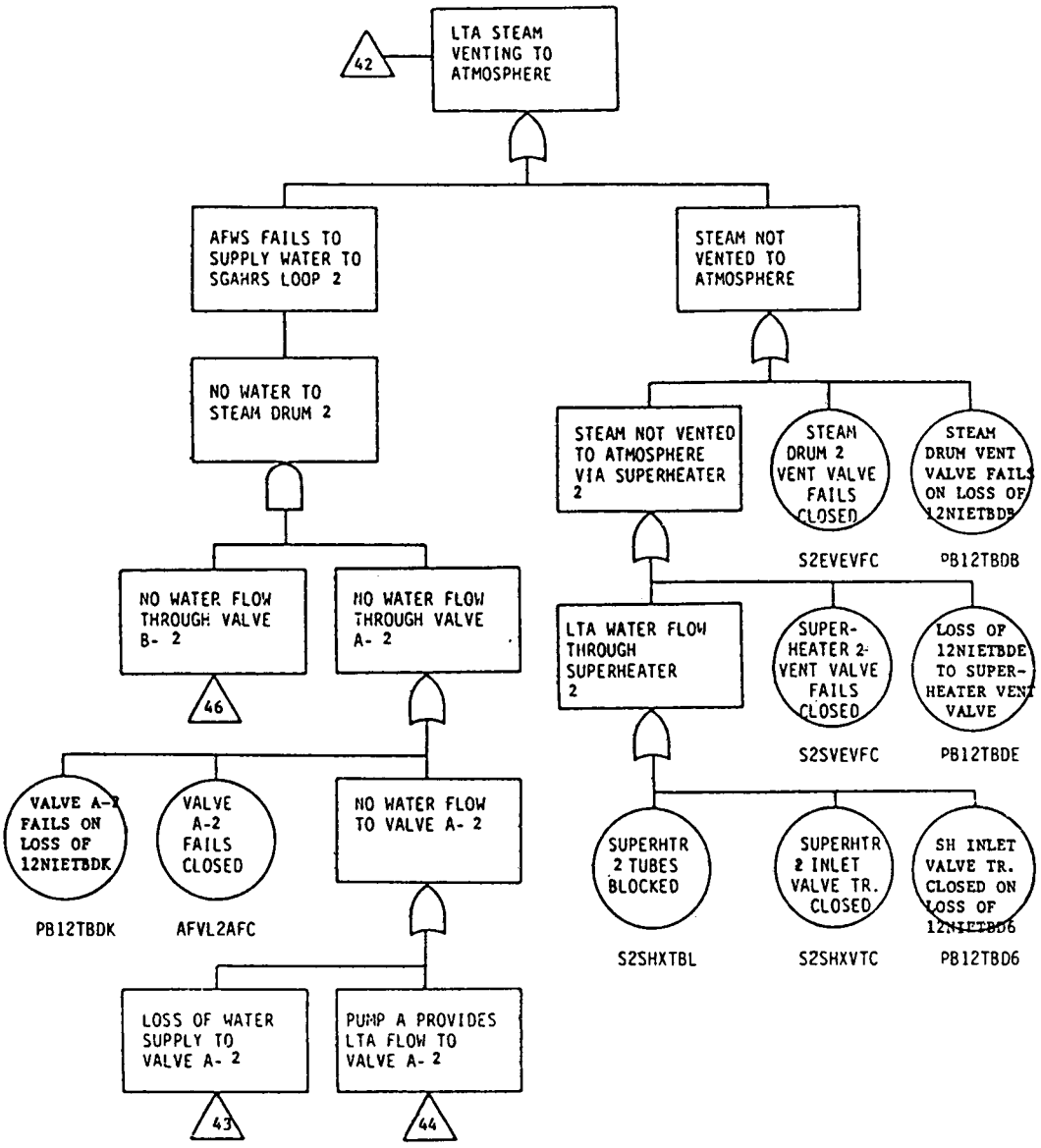

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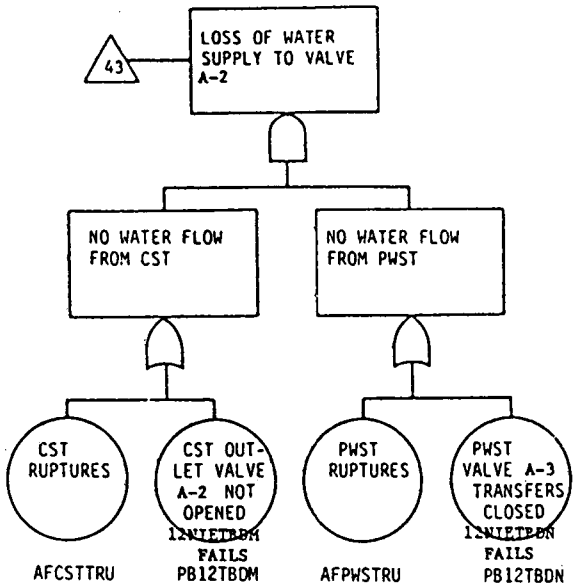

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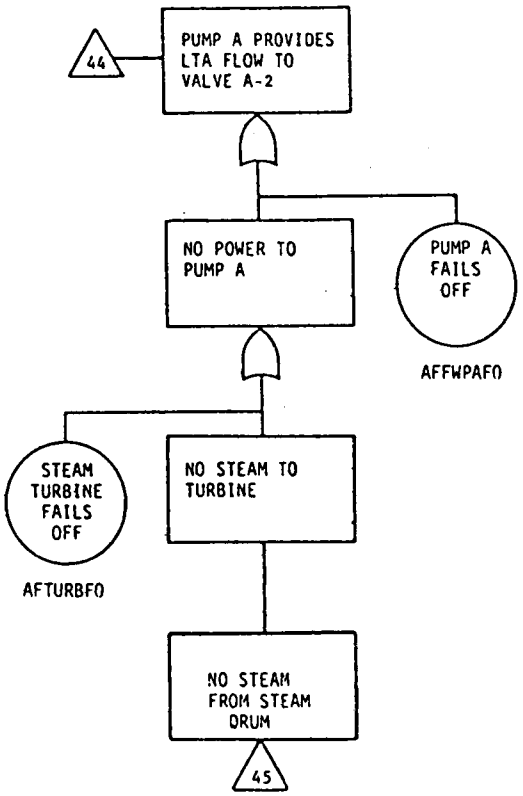

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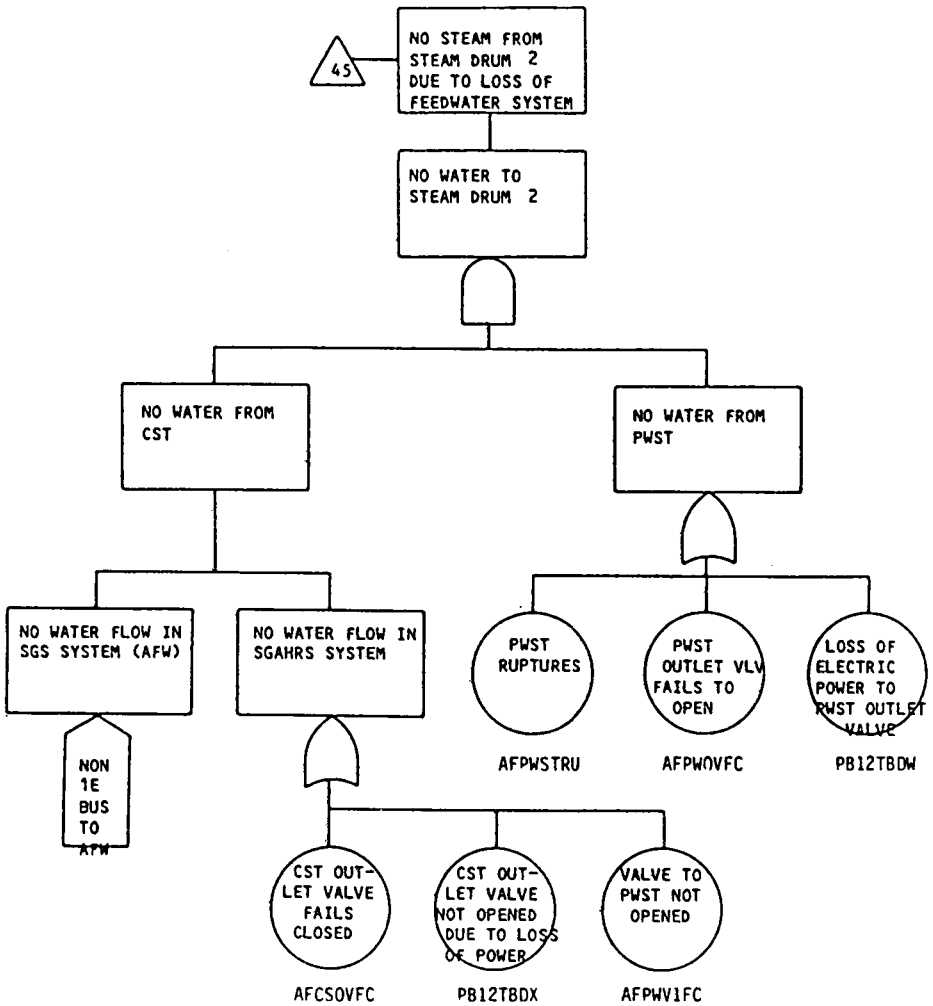

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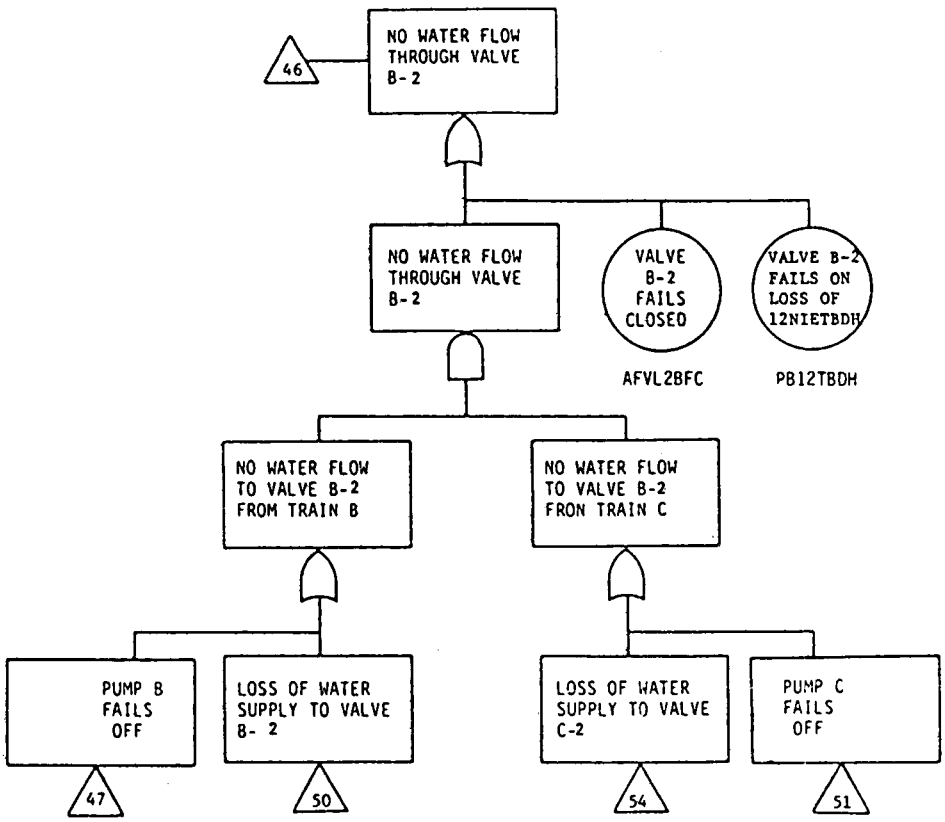

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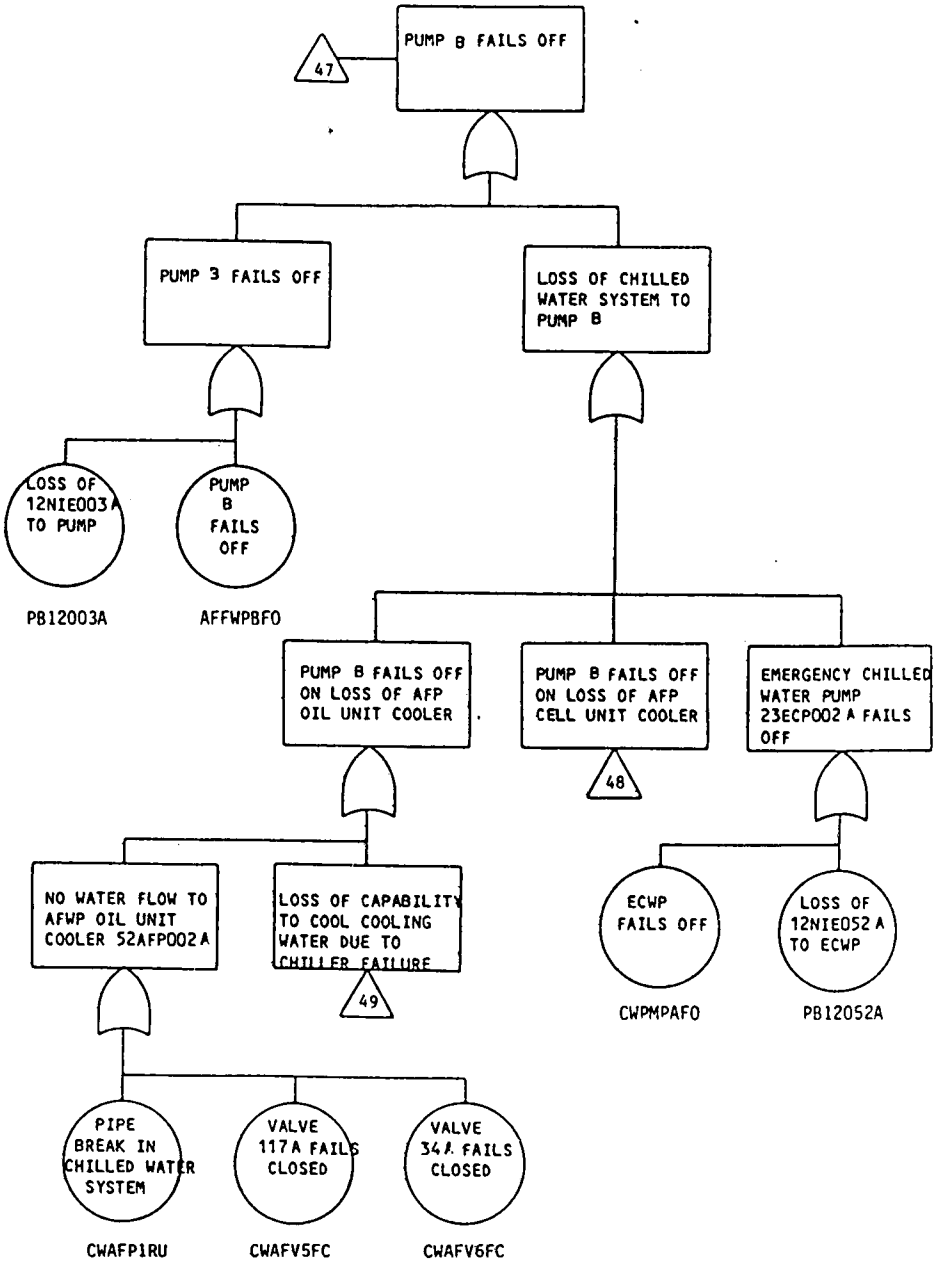

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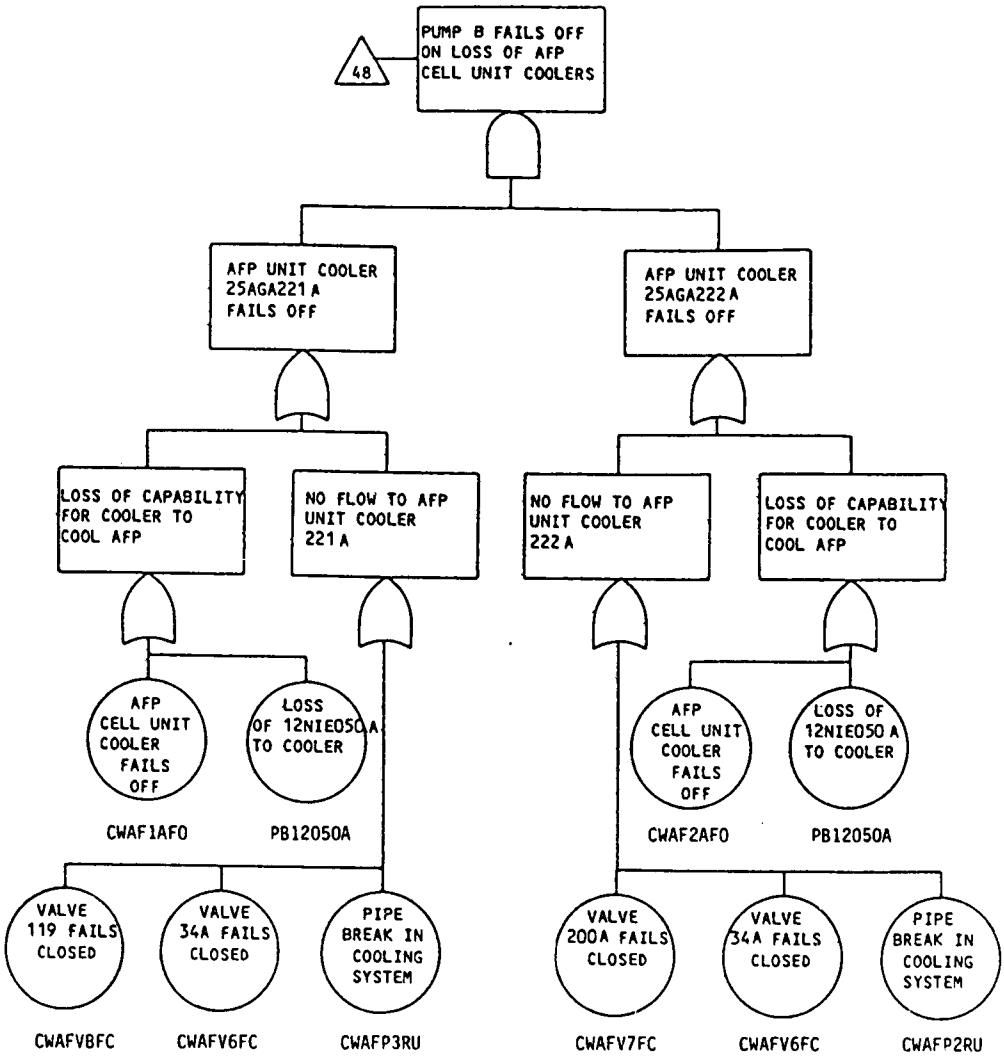

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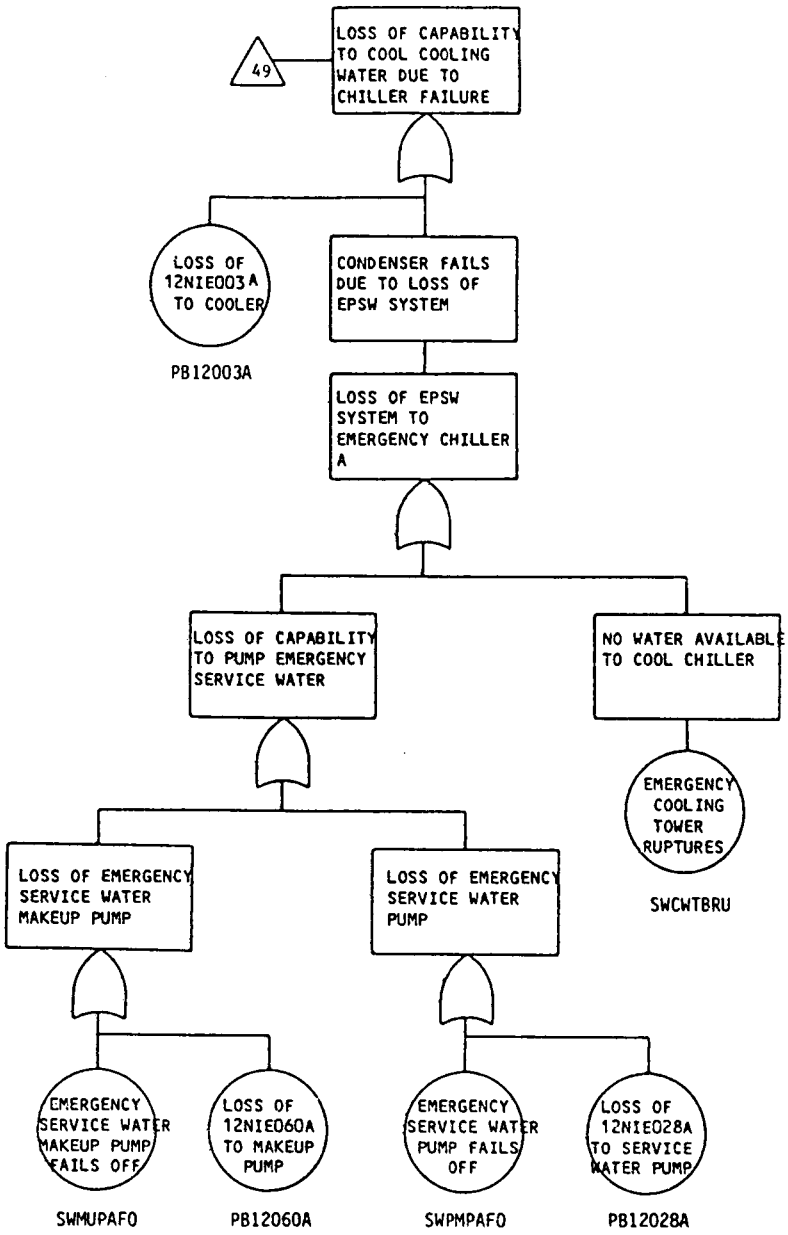

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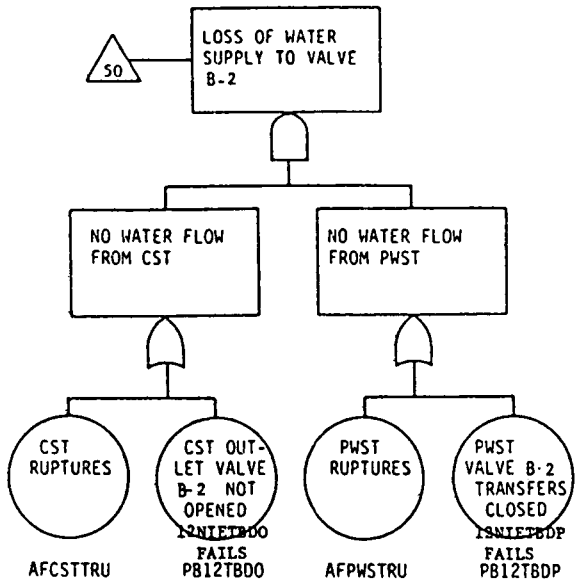

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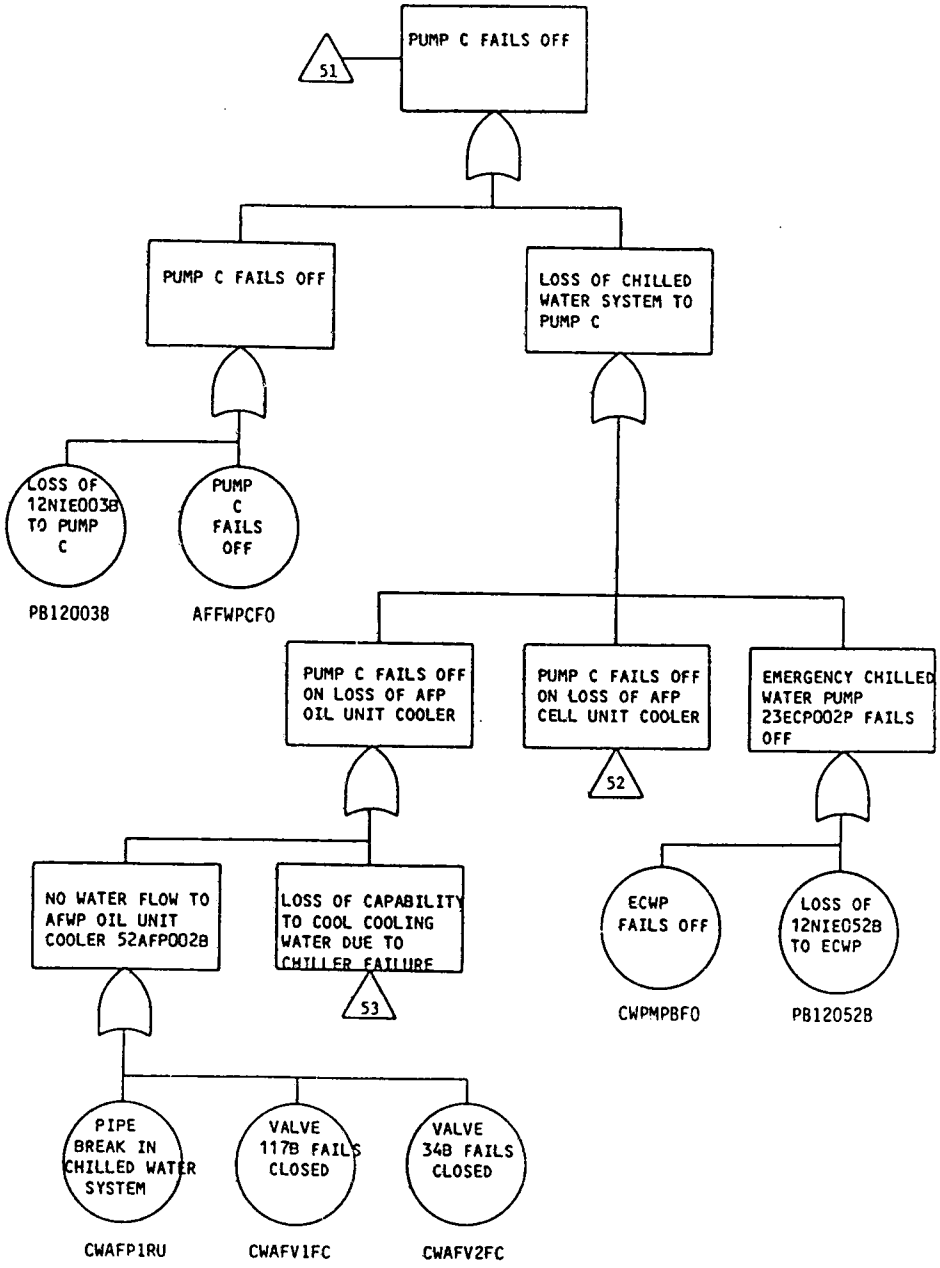

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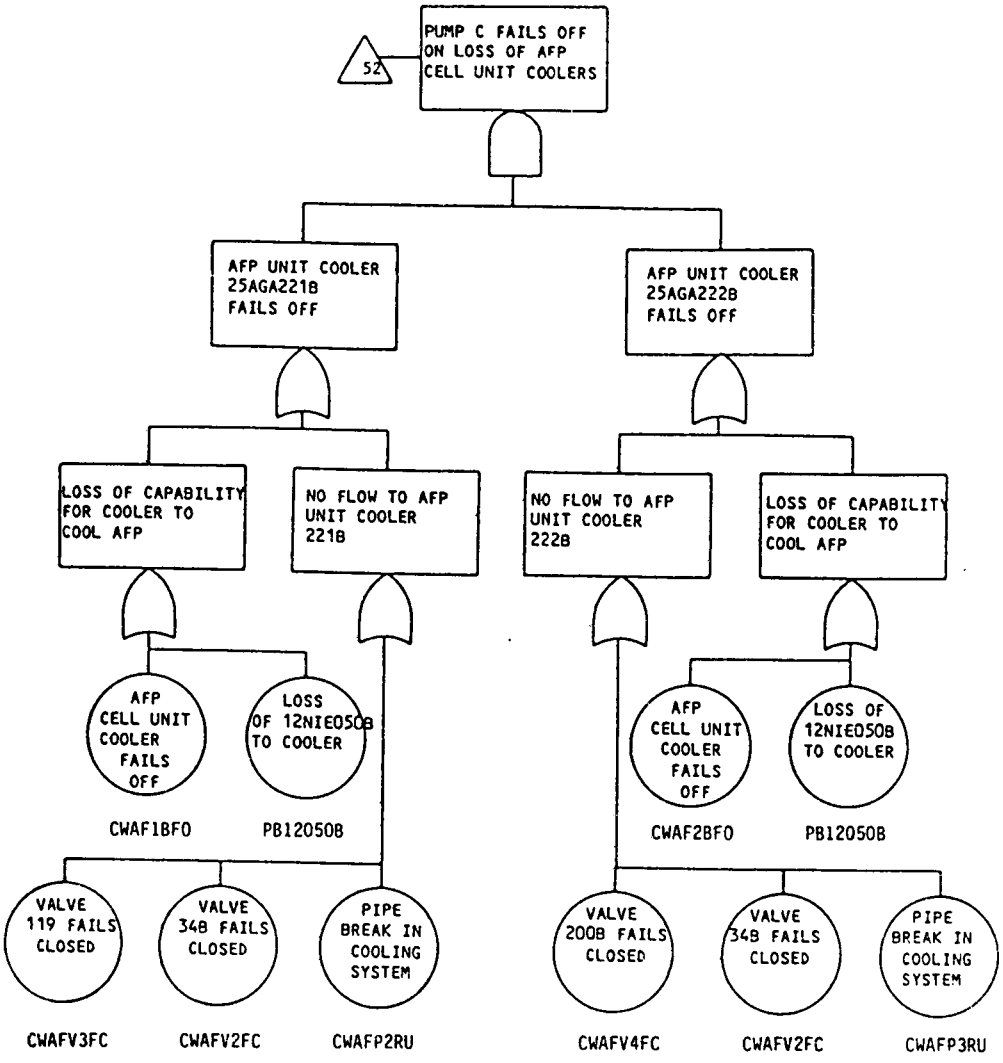

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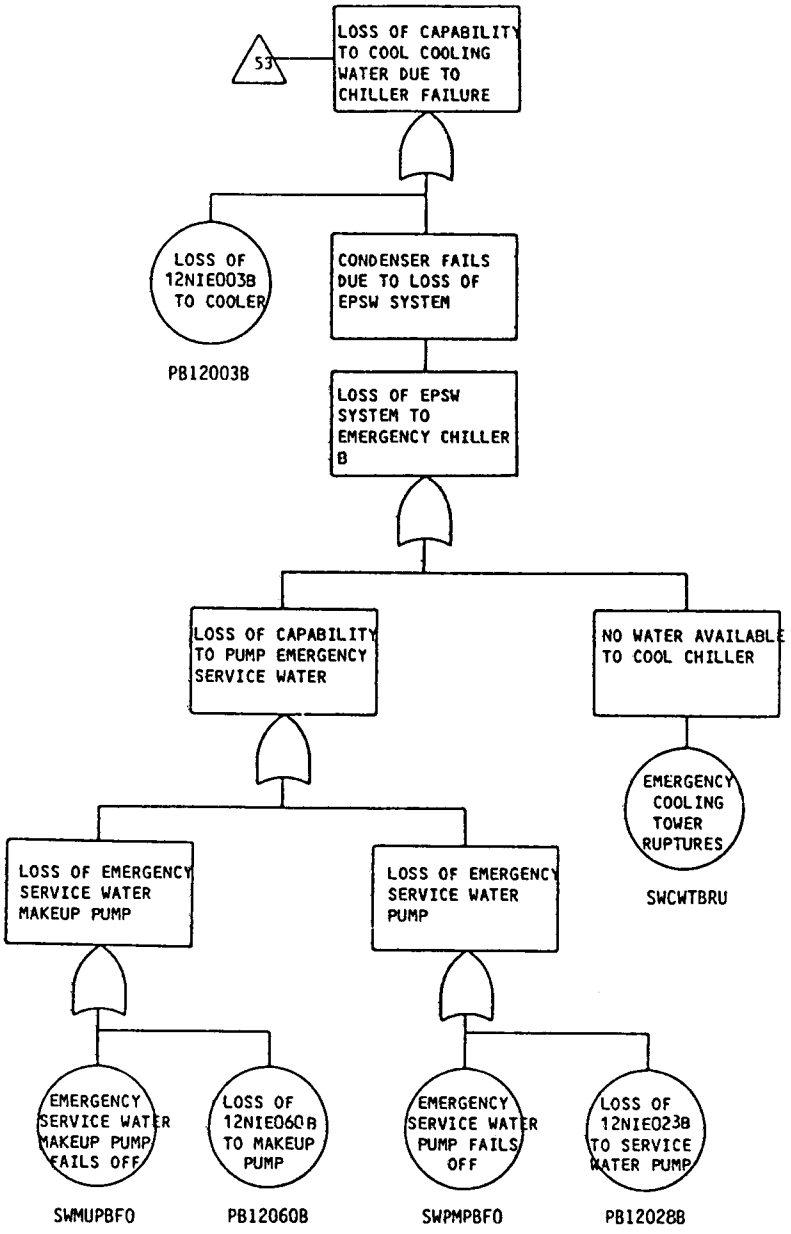

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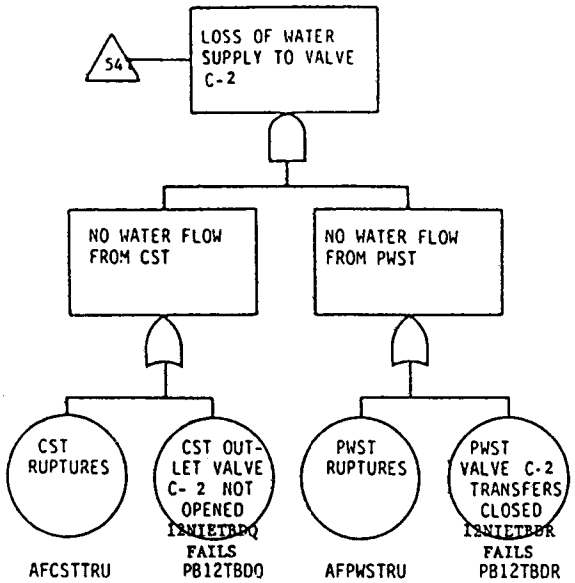

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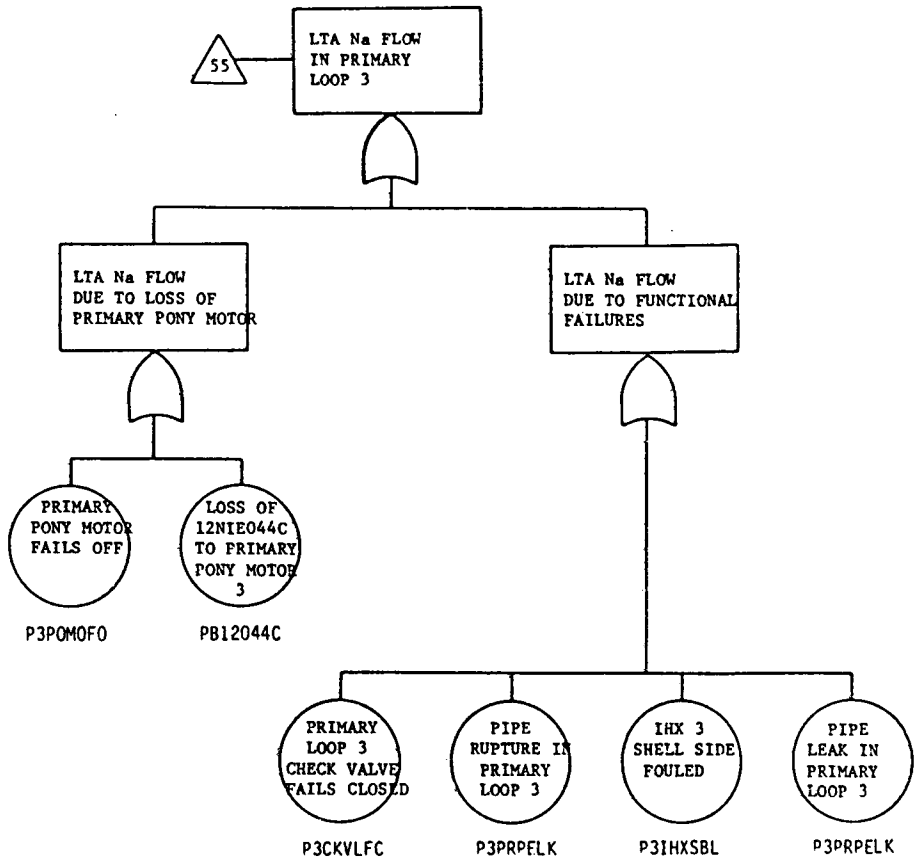

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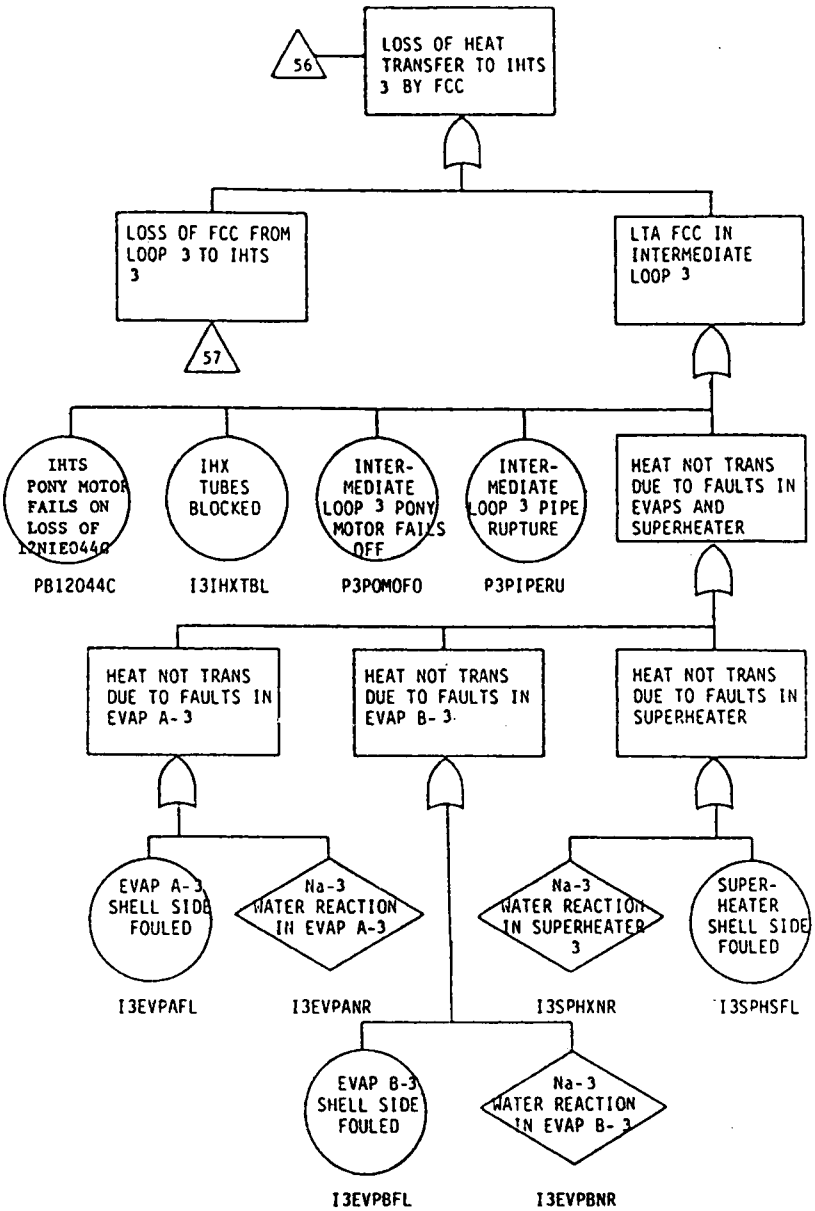

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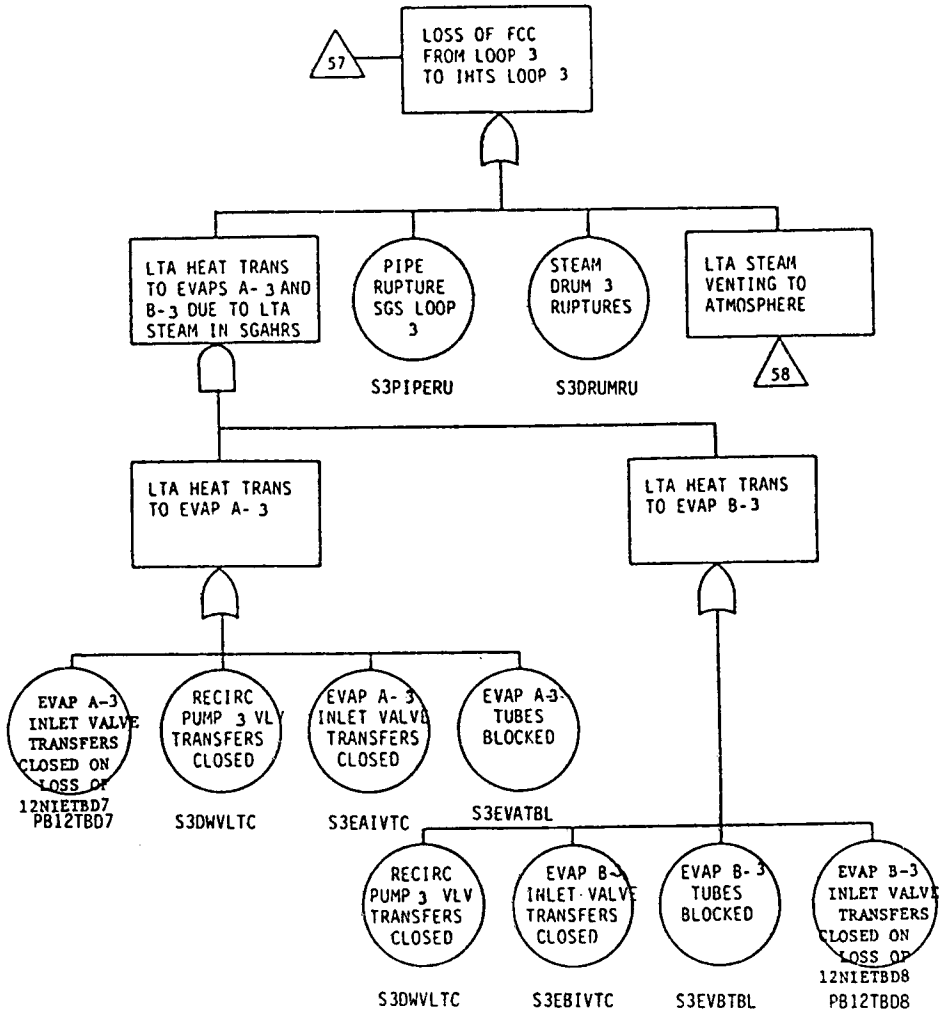

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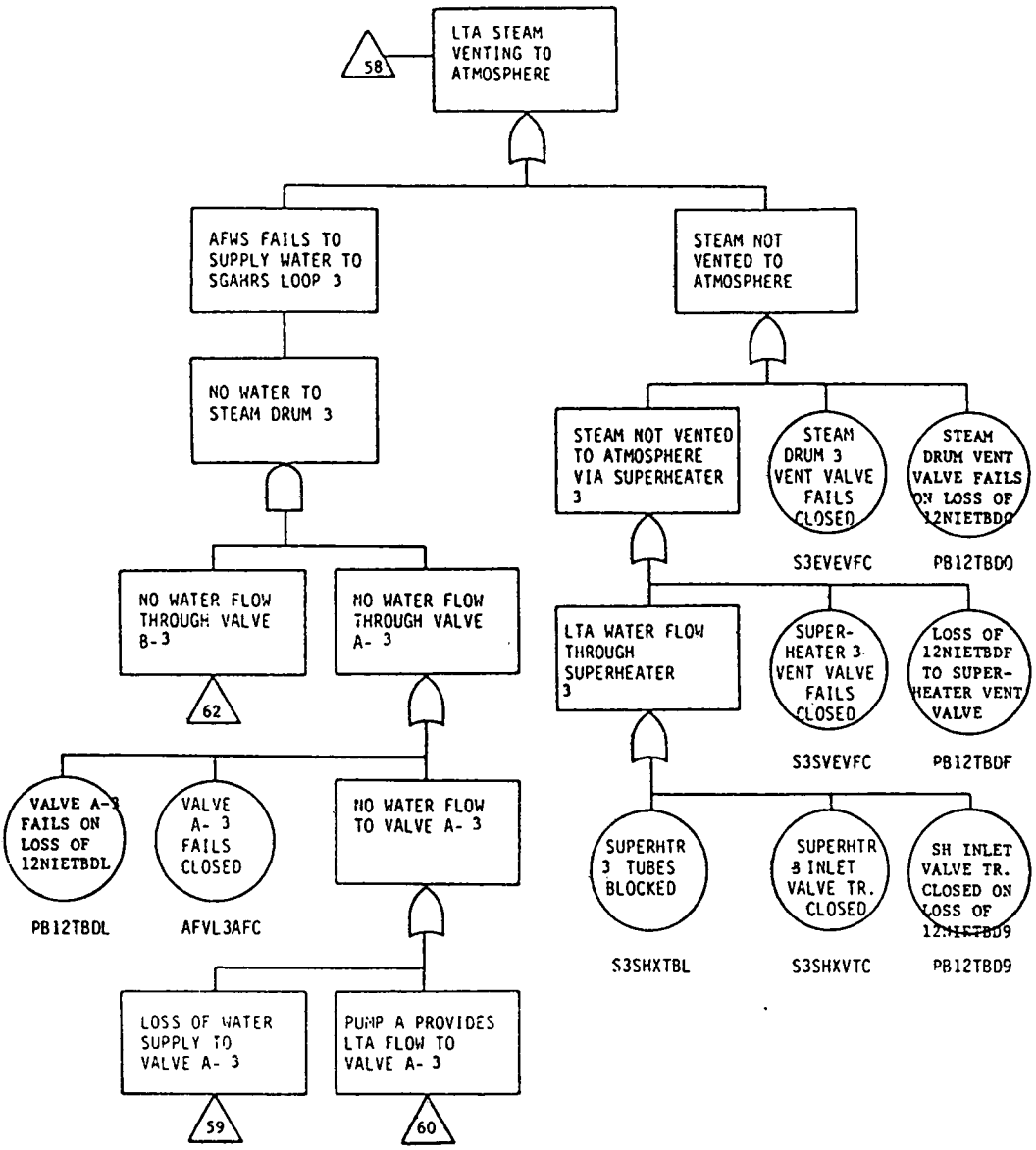

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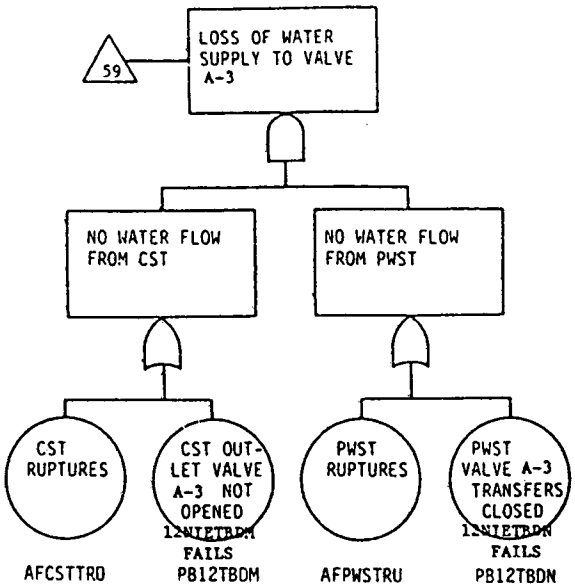

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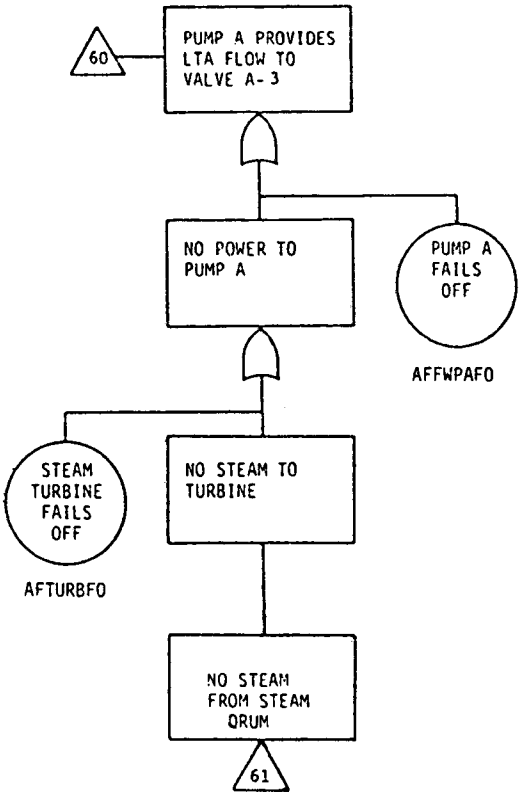

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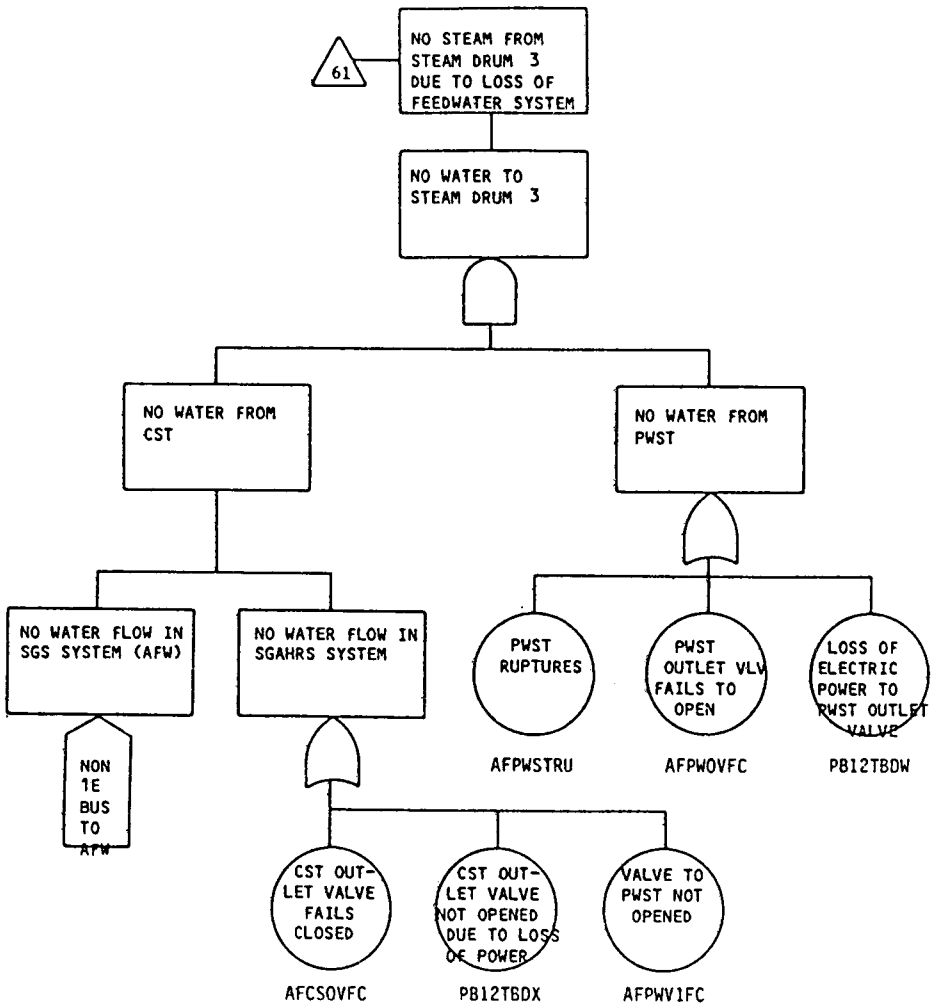

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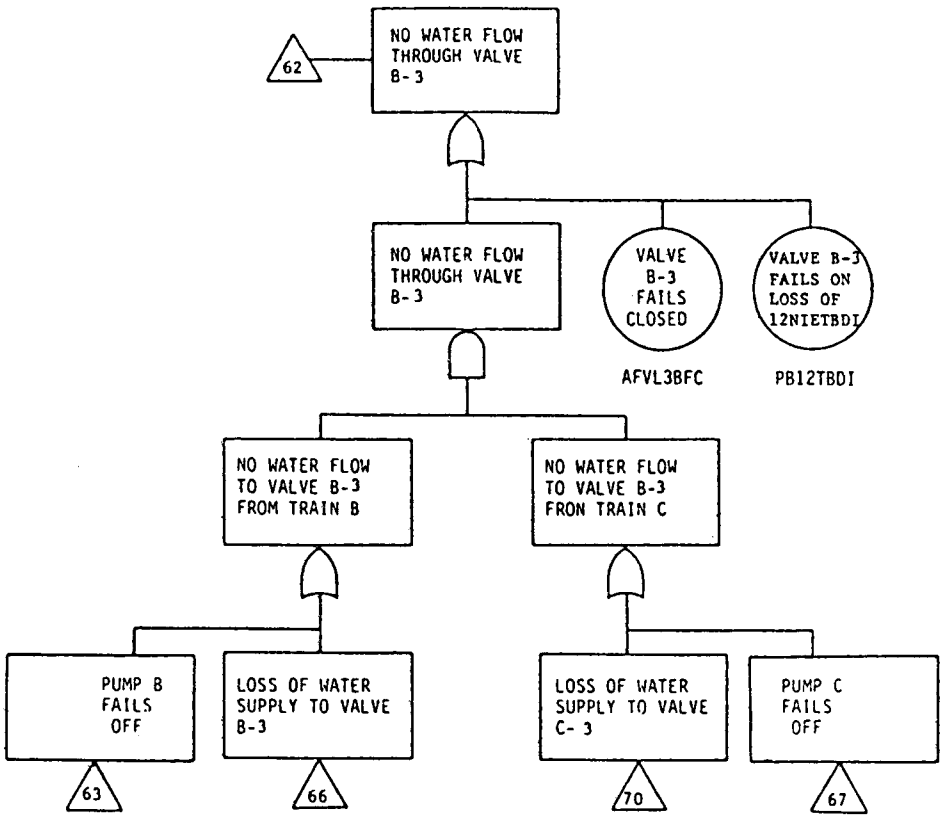

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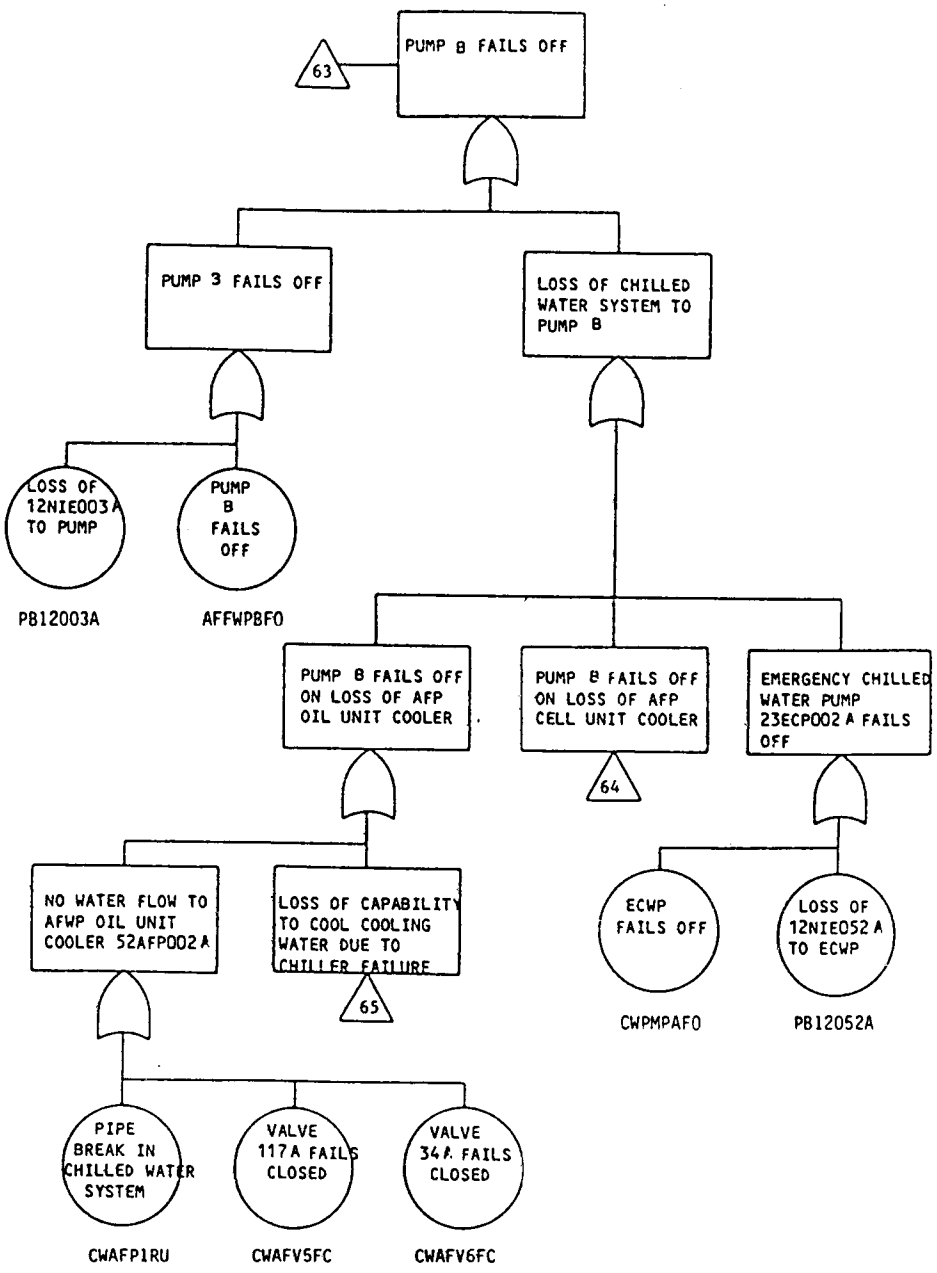

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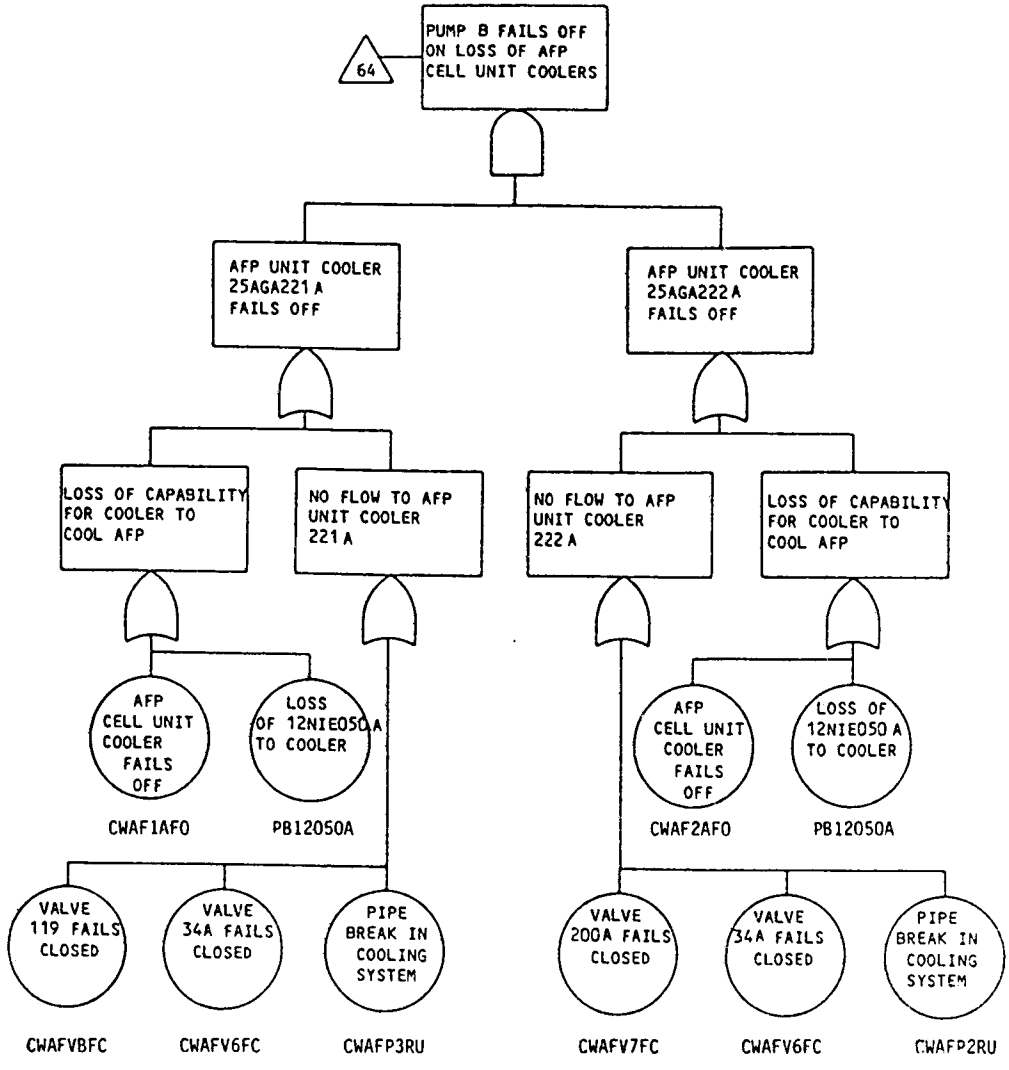

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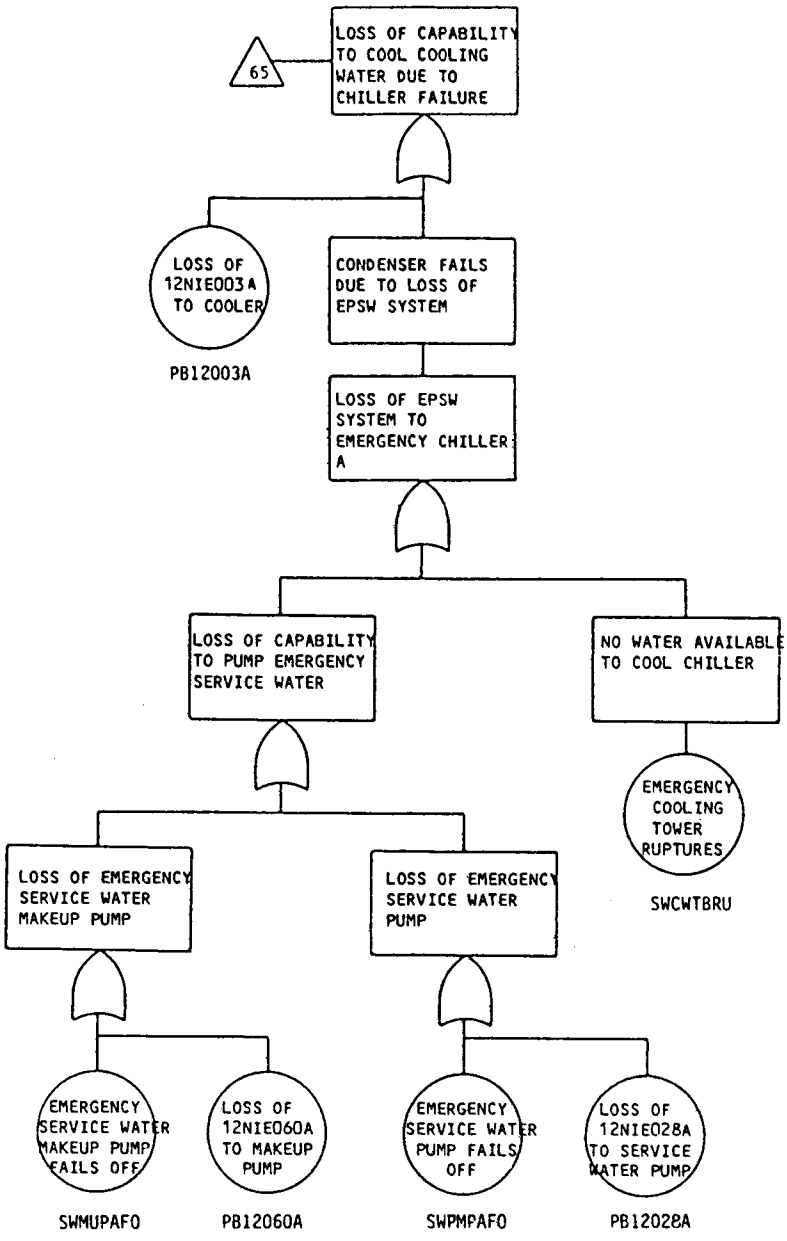

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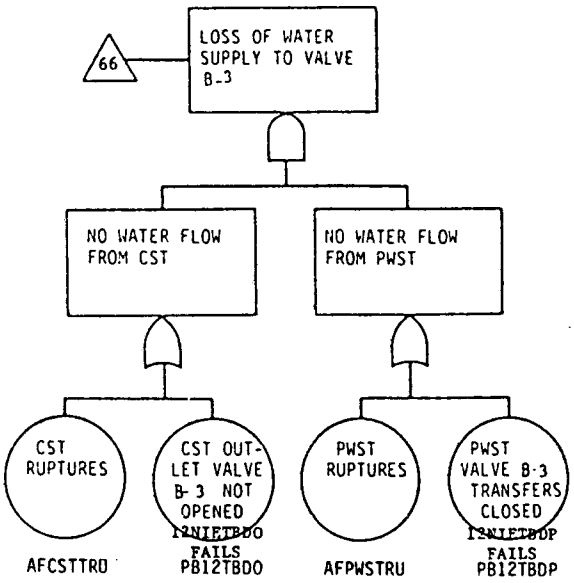

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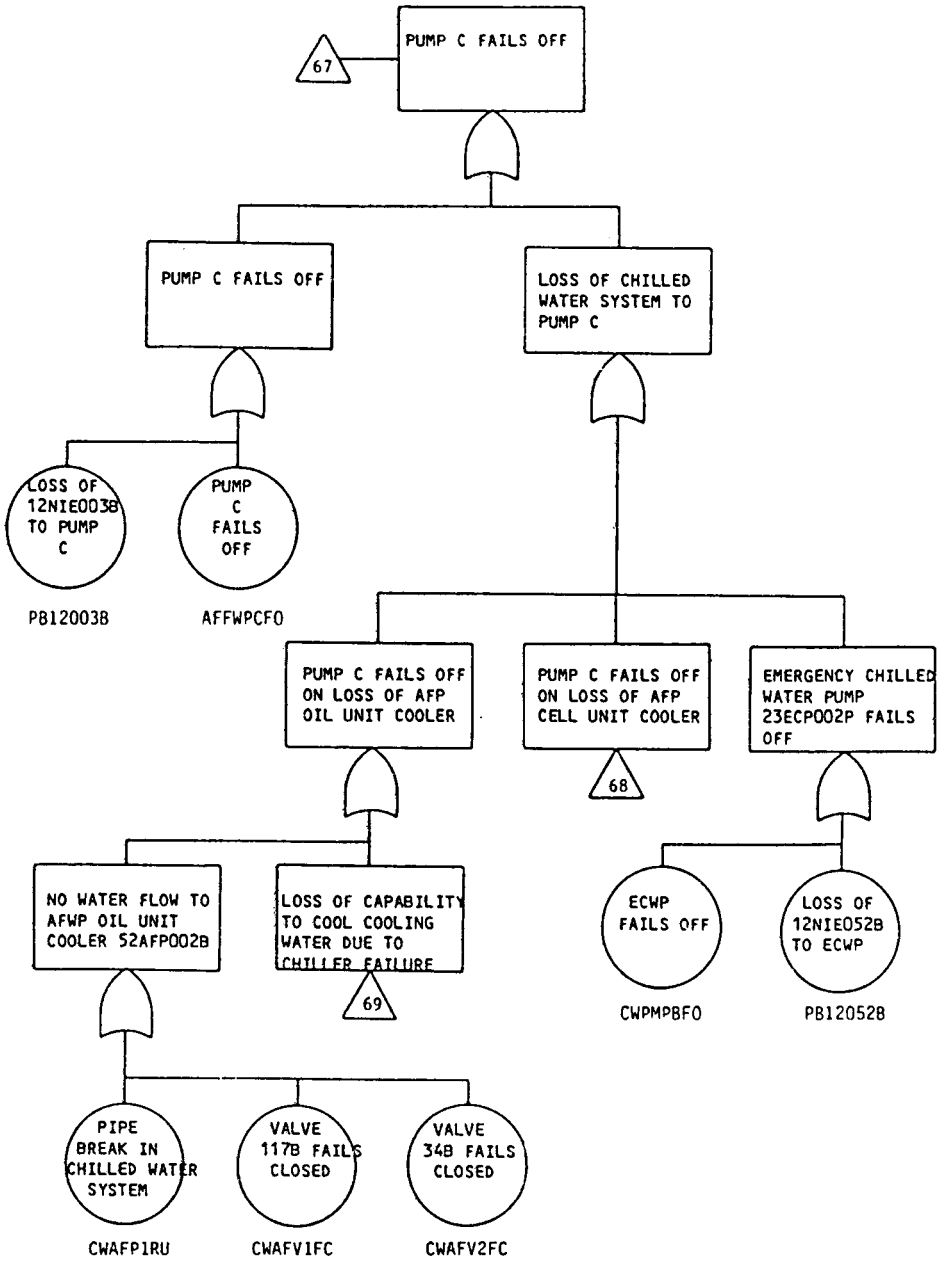

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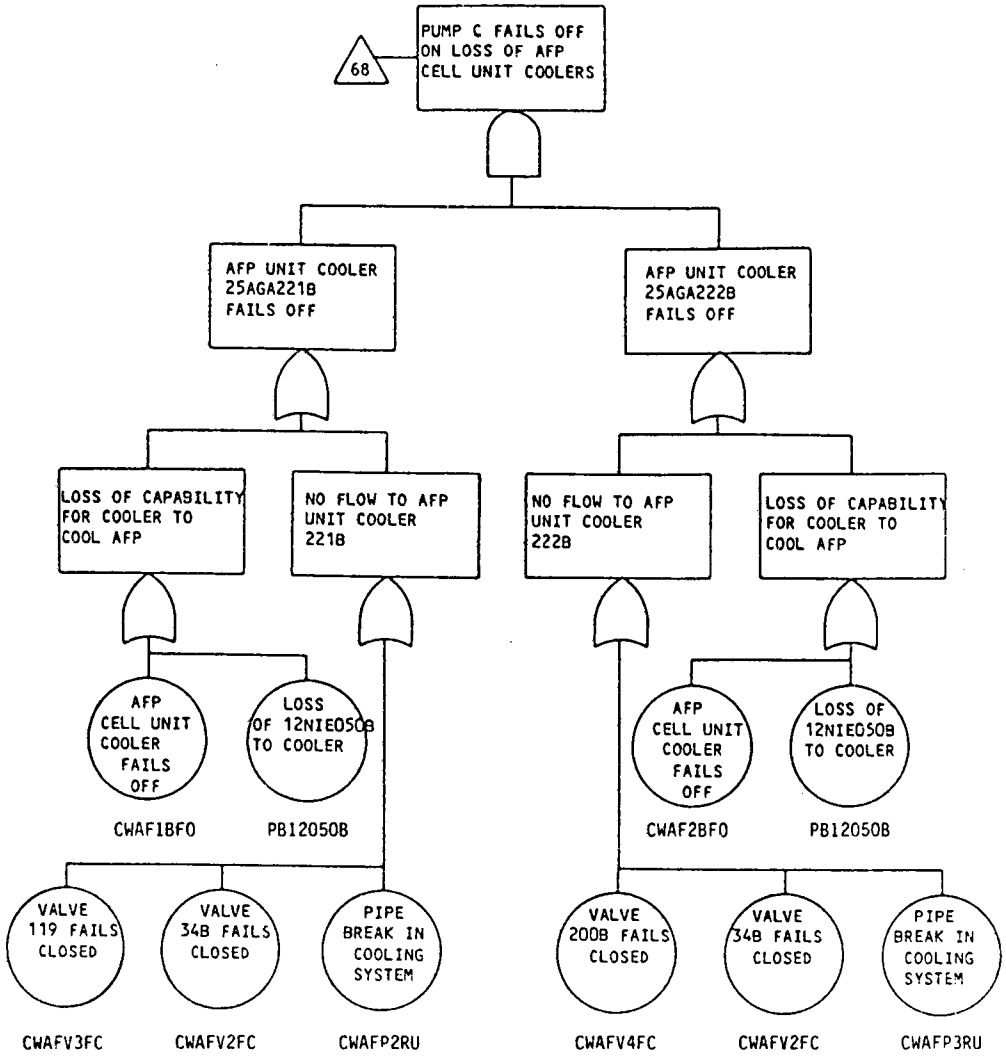

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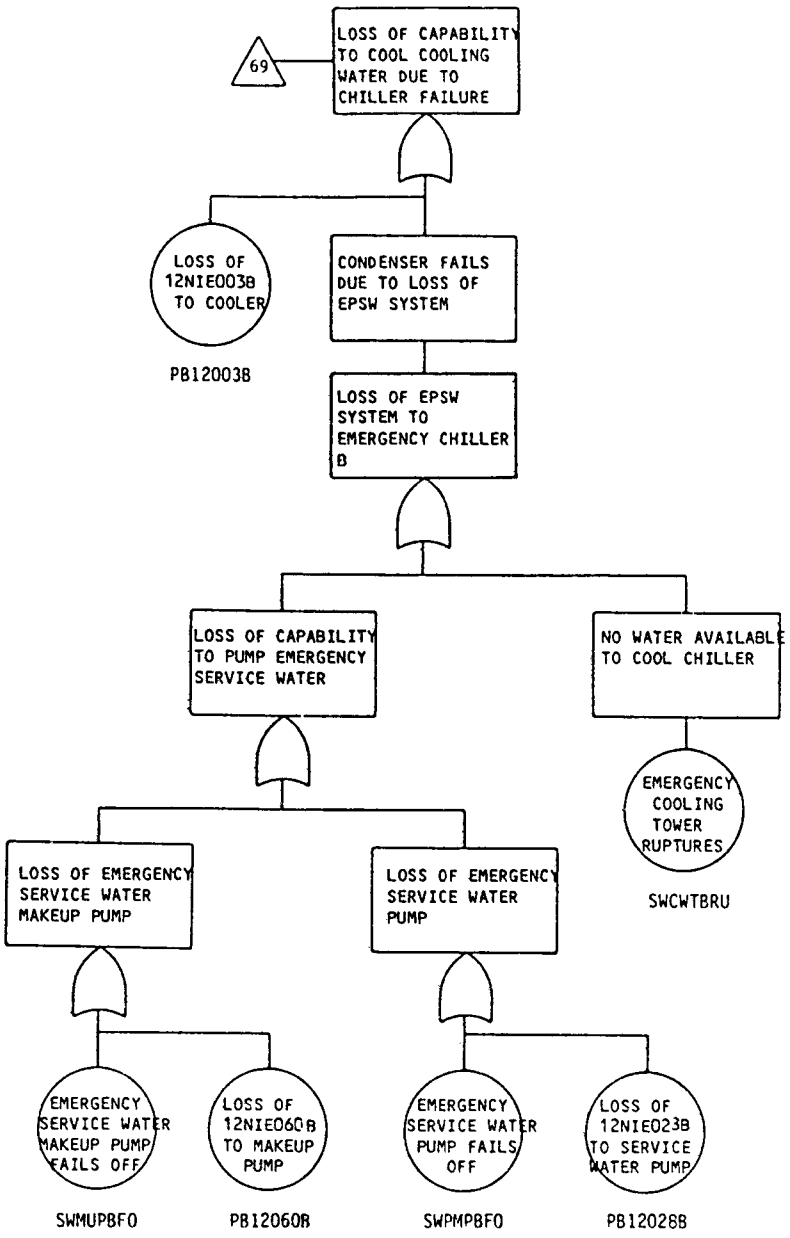

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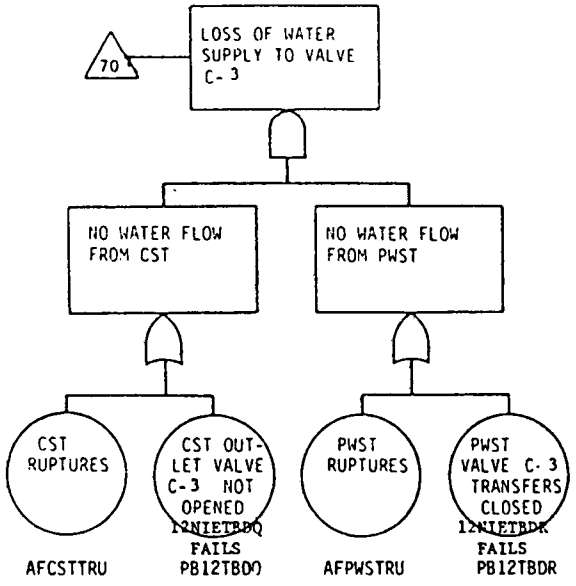

Figure D.1. (continued).

APPENDIX E

CRBRP SHRS LOGIC MODEL CHARACTER IDENTIFICATION CODES

CRBRP SHRS LOGIC MODEL CHARACTER IDENTIFICATION CODES

Basic event descriptions and component names in the CRBRP SHRS logic models are represented by an eight character identification code. The format of the code is shown in Figure E.1. The code may be deciphered by referring to Tables E.1 through E.3.

The logic models for the CRBRP SHRS are presented in Appendix A, Appendix C and Appendix D.

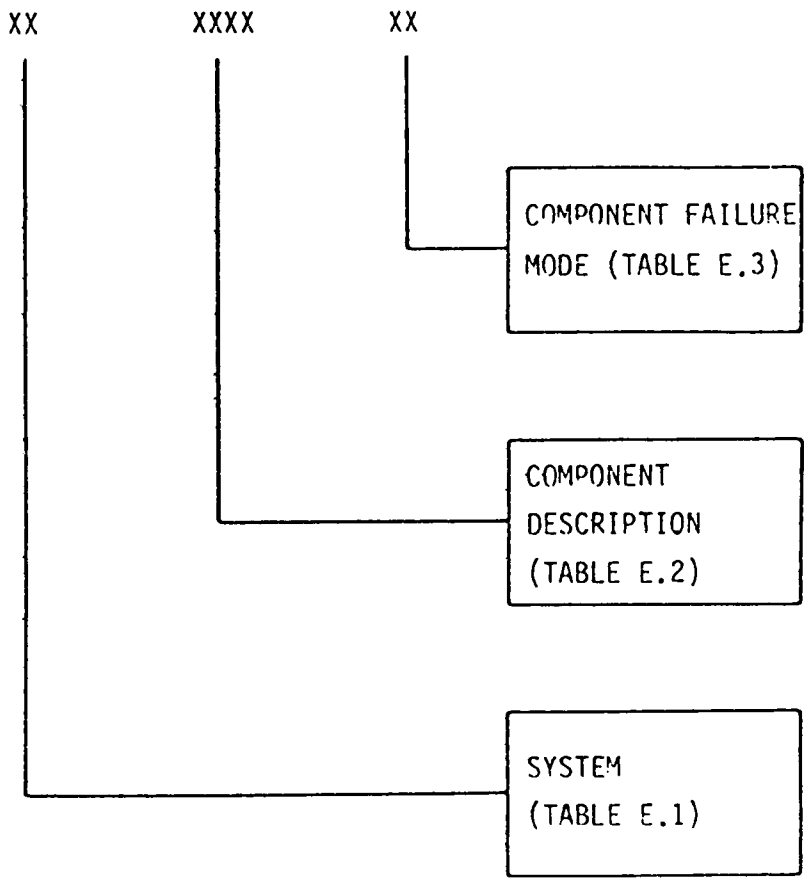

Figure E.1. Identification code format.

Table E.1 System identification codes

CODE	DESCRIPTION
AF	Auxiliary Feedwater System
CW	Emergency Chilled Water System
DH	Direct Heat Removal System
IΘ	Intermediate Heat Transport System Loop Θ
IG	Inert Gas System
PΘ	Primary Heat Transport System Loop Θ
PS	Primary Heat Transport System
RG	Recirculation Gas Cooling System
SΘ	Steam Generator Auxiliary Heat Removal System Loop Θ
SW	Emergency Plant Service Water System
PB	Electrical Power Bus

Table E.2 Component description codes

CODE	DESCRIPTION
ABCθ	ABHX θ Cell Unit Cooler
ABV1	Emergency Chilled Water Valve 195A
ABV2	Emergency Chilled Water Valve 41A
ABV3	Emergency Chilled Water Valve 195B
ABV4	Emergency Chilled Water Valve 41B
ABPθ	ABHX θ Cell Unit Cooler Piping
AFVB	Auxiliary Feedwater Pump Unit Cooler Valve 199A
AF1θ	Auxiliary Feedwater Pump Cell Unit Cooler
AFV1	Auxiliary Feedwater Pump Oil Unit Cooler Valve 117B
AFV2	Auxiliary Feedwater Pump Oil Unit Cooler Valve 34B
AFV3	Auxiliary Feedwater Pump Unit Cooler Valve 119B
AFV4	Auxiliary Feedwater Pump Unit Cooler Valve 200B
AFV5	Auxiliary Feedwater Pump Unit Cooler Valve 117A
AFV6	Auxiliary Feedwater Pump Unit Cooler Valve 34A
AFV7	Auxiliary Feedwater Pump Unit Cooler Valve 200A
AFPθ	Auxiliary Feedwater Pump Oil Unit Cooler Pipe θ
AHPC	Piping Common to Both Airblast Heat Exchangers
AHX1	Airblast Heat Exchanger 1
AHX2	Airblast Heat Exchanger 2
AH1P	Airblast Heat Exchanger 1 Piping
AH2P	Airblast Heat Exchanger 2 Piping
A1IV	Airblast Heat Exchanger 1 Inlet Valve
A2IV	Airblast Heat Exchanger 2 Inlet Valve
A1LV	Airblast Heat Exchanger 1 Loop Valve
A2LV	Airblast Heat Exchanger 2 Loop Valve
A1OV	Airblast Heat Exchanger 1 Outlet Valve
A2OV	Airblast Heat Exchanger 2 Outlet Valve

Table E.2 (continued)

CODE	DESCRIPTION
CKVL	Check Valve
COLθ	Recirculation Gas Train Mθ Cooler
CONθ	Condenser θ
CSTT	Condensate Storage Tank
CSVA	Condensate Storage Tank Valve A
CSVB	Condensate Storage Tank Valve B
CSBC	Condensate Storage Tank Valve C
CTSV	Cold Trap System Valves
CWTB	Cooling Tower Basin
DAVθ	Dewar θ Atmospheric Valves
DEWθ	Dewar θ
DRUM	Steam Drum
DSVθ	Dewar θ Supply Line Valves
DVEV	Steam Drum Vent Valve
DWVL	Recirculation Pump Inlet Valve
EAIV	Evaporator A Inlet Valve
EBIV	Evaporator B Inlet Valve
EVAT	Evaporator A Tubes
EVBT	Evaporator B Tubes
EVPA	Evaporator A
EVPB	Evaporator B
FANθ	Recirculation Gas Train Mθ Fan
FWPA	Feedwater Pump A
FWPB	Feedwater Pump B
FWPC	Feedwater Pump C
IHXT	Intermediate Heat Exchanger Tubes

Table E.2 (continued)

CODE	DESCRIPTION
MPPA	Emergency Plant Service Water Pump A
MPPB	Emergency Plant Service Water Pump B
MUPA	Emergency Plant Service Water Makeup Pump A
MUPB	Emergency Plant Service Water Makeup Pump B
MUP1	Sodium Makeup Pump 1
MUP2	Sodium Makeup Pump 2
NKP1	NaK Pump 1
NKP2	NaK Pump 2
N1TB	Nitrogen Bottles
OFVS	Sodium Overflow Vessel
OHBV	Overflow Heat Exchanger Bypass Valves
OHIV	Overflow Heat Exchanger Inlet Valve
OHXT	Overflow Heat Exchanger Tubes
PIPθ	Recirculation Gas Train Mθ Piping
PMPA	Emergency Service Water Pump A
PMPB	Emergency Service Water Pump B
PMP1	Emergency Chilled Water Pump 1
PMP2	Emergency Chilled Water Pump 2
POMO	Pony Motor
PPMM	Primary Pump Main Motor
PRPE	Primary Piping
PWST	Protected Water Storage Tank
PWVA	Protected Water Storage Tank Valve A
PWVB	Protected Water Storage Tank Valve B
PWVC	Protected Water Storage Tank Valve C
RCAC	Accumulators to RCB Valves
RCBP	Nitrogen Bottle Supply Line To RCB Valves

Table E.2 (continued)

CODE	DESCRIPTION
RCBV	Bottled Nitrogen Supply Line Valves
RCRP	Nitrogen Supply Line Valves To RCB Valves
RCRV	Valves in Nitrogen Supply Line To RCB Valves
RGVS	Reactor Guard Vessel
RSAC	Accumulators to RSB Valves
RSBP	Bottled Nitrogen Supply Line to RSB Valves
RSSP	Nitrogen Supply Line to RSB Valves
RSΘP	Bottled Nitrogen Service Station Piping
RSΘV	Bottled Nitrogen Service Station Valves
RXVS	Reactor Vessel
SHXI	Superheater Inlet Valves
SHXT	Superheater Tubes
SPHS	Superheater Shell
SPHX	Superheater
TRUB	Turbine
VLΘA	Auxiliary Feedwater Valve A-Θ
VLΘB	Auxiliary Feedwater Valve B-Θ

Table E.3 Failure mode codes

CODE	DESCRIPTION
BL	Blocked
FC	Fails Closed
FL	Fouled
FO	Fails Off
FP	Fails Open
LK	Leaks
NA	Not Available
NC	Not Closed
NP	No Power
NR	Sodium Water Reaction
NS	No Steam
RO	Remains On
RU	Rupture
TC	Transfers Closed
TO	Transfers Open

APPENDIX F

TWO AND THREE EVENT MINIMAL CUT SETS FROM THE FUNCTIONAL FAULT TREE LEVEL

Table F.1 Two and three event minimal cut sets for the SHRS systems interaction analysis from the functional level

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	MINIMAL CUT SET NUMBER	COMPONENT FAILURE
1	PSRGVSRU PSRXVSRU	11	P1POMOFO P2CKVLFC P3CKVLFC
2	P1CKVLFC P2CKVLFC P3CKVLFC	12	P1POMOFO P2CKVLFC P3POMOFO
3	P1CKVLFC P2CKVLFC P3POMPFO	13	P1POMOFO P2CKVLFC P3PRPELK
4	P1CKVLFC P2CKVLFC P3PRPELK	14	P1POMOFO P2POMOFO P3CKVLFC
5	P1CKVLFC P2POMOFO P3POMOFO	15	P1POMOFO P2POMOFO P3POMOFO
6	P1CKVLFC P2POMOFO P3CKVLFC	16	P1POMOFO P2POMOFO P3PRPELK
7	P1CKVLFC P2POMOFO P3PRPELK	17	P1POMOFO P2PRPELK P3CKVLFC
8	P1CKVLFC P2PRPELK P3CKVLFC	18	DHMUP1TO AFCSTTRU AFPWSTRU
9	P1CKVLFC P2PRPELK P3POMOFO	19	DHMUP2TO AFCSTTRU AFPWSTRU
10	P1CKVLFC P2PRPELK P3PRPELK		

Table F.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	MINIMAL CUT SET NUMBER	COMPONENT FAILURE
20	P1PRPELK P2PRPELK P3PRPELK	30	P1POMOFO P2PRPELK P3POMOFO
21	DHCTSVNC AFCSTTRU AFPWSTRU	31	P1POMOFO P2PRPELK P3PRPELK
22	DHOHIVFC AFCSTTRU AFPWSTRU	32	P1PRPELK P2CKVLFC P3CKVLFC
23	DHOHBVFC AFCSTTRU AFPWSTRU	33	P1PRPELK P2CKVLFC P3POMOFO
24	DHRLVLFC AFCSTTRU AFPWSTRU	34	P1PRPELK P2CKVLFC P3PRPELK
25	DHCKVLFC AFCSTTRU AFPWSTRU	35	P1PRPELK P2POMOFO P3CKVLFC
26	DHOFVSRU AFCSTTRU AFPWSTRU	36	P1PRPELK P2POMOFO P3POMOFO
27	DHPRPELK AFCSTTRU AFPWSTRU	37	P1PRPELK P2POMOFO P3PRPELK
28	DHOHXTBL AFCSTTRU AFPWSTRU	38	P1PRPELK P2PRPELK P3CKVLFC
29	DHAHCPRU AFCSTTRU AFPWSTRU	39	P1PRPELK P2PRPELK P3POMOFO

APPENDIX G

TWO AND THREE EVENT MINIMAL CUT SETS FROM THE SYSTEMS INTERACTION FAULT TREE AT THE PRIMARY INTERFACE LEVEL

Table G.1 Two and three event minimal cut sets for the SHRS systems interaction analysis from the primary interface level

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO
1	PSRGVSRU	-
	PSRXVSRU	-
2	ARTURBFO	-
	SWCWTBRU	AFFWPBFO
		AFFWPCFO
		DHAHX1FO
		DHAHX2FO
3	AFFWPAFO	-
	SWCWTBRU	AFFWPBFO
		AFFWPCFO
		DHAHX1FO
		DHAHX2FO
4	P1CKVLFC	-
	P2CKVLFC	-
	P3CKVLFC	-
5	P1CKVLFC	-
	P2CKVLFC	-
	P3POMPFO	-
6	P1CKVLFC	-
	P2CKVLFC	-
	P3PRPELK	-
7	P1CKVLFC	-
	P2POMOFO	-
	P3POMOFO	-
8	P1CKVLFC	-
	P2POMOFO	-
	P3CKVLFC	-
9	P1CKVLFC	-
	P2POMOFO	-
	P3PRPELK	-

Table G.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO
10	P1CKVLFC	-
	P2PRPELK	-
	P3CKVLFC	-
11	P1CKVLFC	-
	P2PRPELK	-
	P3POMOFO	-
12	P1CKVLFC	-
	P2PRPELK	-
	P3PRPELK	-
13	P1POMOFO	-
	P2CKVLFC	-
	P3CKVLFC	-
14	P1POMOFO	-
	P2CKVLFC	-
	P3POMOFO	-
15	P1POMOFO	-
	P2CKVLFC	-
	P3PRPELK	-
16	P1POMOFO	-
	P2POMOFO	-
	P3CKVLFC	-
17	P1POMOFO	-
	P2POMOFO	-
	P3POMOFO	-
18	P1POMOFO	-
	P2POMOFO	-
	P3PRPELK	-
19	P1POMOFO	-
	P2PRPELK	-
	P3CKVLFC	-

Table G.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO
20	P1POMOFO	-
	P2PRPELK	-
	P3POMOFO	-
21	P1POMOFO	-
	P2PRPELK	-
	P3PRPELK	-
22	P1PRPELK	-
	P2CKVLFC	-
	P3CKVLFC	-
23	P1PRPELK	-
	P2CKVLFC	-
	P3POMOFO	-
24	P1PRPELK	-
	P2CKVLFC	-
	P3PRPELK	-
25	P1PRPELK	-
	P2POMOFO	-
	P3CKVLFC	-
26	P1PRPELK	-
	P2POMOFO	-
	P3POMOFO	-
27	P1PRPELK	-
	P2POMOFO	-
	P3PRPELK	-
28	P1PRPELK	-
	P2PRPELK	-
	P3CKVLFC	-
29	P1PRPELK	-
	P2PRPELK	-
	P3POMOFO	-

Table G.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO
30	P1PRPELK	-
	P2PRPELK	-
	P3PRPELK	-
31	DHCTSVNC	-
	AFCSTTRU	-
	AFPWSTRU	-
32	DHOHIVFC	-
	AFCSTTRU	-
	AFPWSTRU	-
33	DHOHBVFC	-
	AFCSTTRU	-
	AFPWSTRU	-
34	DHRLVLFC	-
	AFCSTTRU	-
	AFPWSTRU	-
35	DHCKVLFC	-
	AFCSTTRU	-
	AFPWSTRU	-
36	DHOFVSRU	-
	AFCSTTRU	-
	AFPWSTRU	-
37	DHPRPELK	-
	AFCSTTRU	-
	AFPWSTRU	-
38	DHOHXTBL	-
	AFCSTTRU	-
	AFPWSTRU	-
39	DHAHCPRU	-
	AFCSTTRU	-
	AFPWSTRU	-

Table G.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO
40	DHMUP1TO	-
	AFCSTTRU	-
	AFPWSTRU	-
41	DHMUP2TO	-
	AFCSTTRU	-
	AFPWSTRU	-
42	P1CKVLFC	-
	P2CKVLFC	-
	PB12044C	P3POMOFO
43	P1CKVLFC	-
	PB12050B	P2POMOFO
	P3CKVLFC	-
44	P1CKVLFC	-
	PB12050B	P2POMOFO
	PB12044C	P3POMOFO
45	P1CKVLFC	-
	PB12050B	P2POMOFO
	P3PRPELK	-
46	P1CKVLFC	-
	P2PRPELK	-
	PB12044C	P3POMOFO
47	PB12050A	P1POMOFO
	P2CKVLFC	-
	P3CKVLFC	-
48	PB12050A	P1POMOFO
	P2CKVLFC	-
	PB12044C	P3POMOFO
49	PB12050A	P1POMOFO
	P2CKVLFC	-
	P3PRPELK	-

Table G.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO
50	PB12050A	P1POMOFO
	PB12050B	P2POMOFO
	P3CKVLFC	-
51	PB12050A	P1POMOFO
	PB12050B	P2POMOFO
	PB12044C	P3POMOFO
52	PB12050A	P1POMOFO
	PB12050B	P2POMOFO
	P3PRPELK	-
53	PB12050A	P1POMOFO
	P2PRPELK	-
	P3CKVLFC	-
54	PB12050A	P1POMOFO
	P2PRPELK	-
	PB12044C	P3POMOFO
55	PB12050A	P1POMOFO
	P2PRPELK	-
	P3PRPELK	-
56	P1PRPELK	-
	P2CKVLFC	-
	PB12044C	P3POMOFO
57	P1PRPELK	-
	PB12050B	P2POMOFO
	P3CKVLFC	-
58	P1PRPELK	-
	PB12050B	P2POMOFO
	PB12044C	P3POMOFO
59	P1PRPELK	-
	PB12050B	P2POMOFO
	P3PRPELK	-

Table G.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO
60	P1PRPELK	-
	P2PRPELK	-
	PB12044C	P3POMOFO
61	PB12041A	DHMUP1TO
	AFCSTTRU	-
	AFPWSTRU	-
62	PB12041B	DHMUP2TO
	AFCSTTRU	-
	AFPWSTRU	-
63	RGPIPARU	DHMUP1TO
	AFCSTTRU	-
	AFPWSTRU	-
64	RGPIPBRU	DHMUP2TO
	AFCSTTRU	-
	AFPWSTRU	-

APPENDIX H

TWO AND THREE EVENT MINIMAL CUT SETS FROM THE SYSTEMS INTERACTION FAULT TREE AT THE SECONDARY INTERFACE LEVEL

Table H.1 Two and three event minimal cut sets for the SHRS systems interaction analysis from the secondary interface level

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
1	PSRGVSRU	-	-
	PSRXVSRU	-	-
2	ARTURBFO	-	-
	SWCWTBRU	AFFWPBFO	-
		AFFWPCFO	-
		DHAHX1FO	-
		DHAHX2FO	-
3	AFFWPAFO	-	-
	SWCWTBRU	AFFWPBFO	-
		AFFWPCFO	-
		DHAHX1FO	-
		DHAHX2FO	-
4	P1CKVLFC	-	-
	P2CKVLFC	-	-
	P3CKVLFC	-	-
5	P1CKVLFC	-	-
	P2CKVLFC	-	-
	P3POMPFO	-	-
6	P1CKVLFC	-	-
	P2CKVLFC	-	-
	P3PRPELK	-	-
7	P1CKVLFC	-	-
	P2POMOFO	-	-
	P3POMOFO	-	-
8	P1CKVLFC	-	-
	P2POMOFO	-	-
	P3CKVLFC	-	-
9	P1CKVLFC	-	-
	P2POMOFO	-	-
	P3PRPELK	-	-

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
10	P1CKVLFC	-	-
	P2PRPELK	-	-
	P3CKVLFC	-	-
11	P1CKVLFC	-	-
	P2PRPELK	-	-
	P3POMOFO	-	-
12	P1CKVLFC	-	-
	P2PRPELK	-	-
	P3PRPELK	-	-
13	P1POMOFO	-	-
	P2CKVLFC	-	-
	P3CKVLFC	-	-
14	P1POMOFO	-	-
	P2CKVLFC	-	-
	P3POMOFO	-	-
15	P1POMOFO	-	-
	P2CKVLFC	-	-
	P3PRPELK	-	-
16	P1POMOFO	-	-
	P2POMOFO	-	-
	P3CKVLFC	-	-
17	P1POMOFO	-	-
	P2POMOFO	-	-
	P3POMOFO	-	-
18	P1POMOFO	-	-
	P2POMOFO	-	-
	P3PRPELK	-	-
19	P1POMOFO	-	-
	P2PRPELK	-	-
	P3CKVLFC	-	-

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
20	P1POMOFO	-	-
	P2PRPELK	-	-
	P3POMOFO	-	-
21	P1POMOFO	-	-
	P2PRPELK	-	-
	P3PRPELK	-	-
22	P1PRPELK	-	-
	P2CKVLFC	-	-
	P3CKVLFC	-	-
23	P1PRPELK	-	-
	P2CKVLFC	-	-
	P3POMOFO	-	-
24	P1PRPELK	-	-
	P2CKVLFC	-	-
	P3PRPELK	-	-
25	P1PRPELK	-	-
	P2POMOFO	-	-
	P3CKVLFC	-	-
26	P1PRPELK	-	-
	P2POMOFO	-	-
	P3POMOFO	-	-
27	P1PRPELK	-	-
	P2POMOFO	-	-
	P3PRPELK	-	-
28	P1PRPELK	-	-
	P2PRPELK	-	-
	P3CKVLFC	-	-
29	P1PRPELK	-	-
	P2PRPELK	-	-
	P3POMOFO	-	-

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
30	P1PRPELK	-	-
	P2PRPELK	-	-
	P3PRPELK	-	-
31	DHCTSVNC	-	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
32	DHOHIVFC	-	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
33	DHOHBVFC	-	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
34	DHRLVLFC	-	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
35	DHCKVLFC	-	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
36	DHOFVSRU	-	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
37	DHPRPELK	-	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
38	DHOHXTBL	-	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
39	DHAHCPRU	-	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
40	DHMUP1TO	-	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
41	DHMUP2TO	-	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
42	P1CKVLFC	-	-
	P2CKVLFC	-	-
	PB12044C	P3POMOFO	-
43	P1CKVLFC	-	-
	PB12050B	P2POMOFO	-
	P3CKVLFC	-	-
44	P1CKVLFC	-	-
	PB12050B	P2POMOFO	-
	PB12044C	P3POMOFO	-
45	P1CKVLFC	-	-
	PB12050B	P2POMOFO	-
	P3PRPELK	-	-
46	P1CKVLFC	-	-
	P2PRPELK	-	-
	PB12044C	P3POMOFO	-
47	PB12050A	P1POMOFO	-
	P2CKVLFC	-	-
	P3CKVLFC	-	-
48	PB12050A	P1POMOFO	-
	P2CKVLFC	-	-
	PB12044C	P3POMOFO	-
49	PB12050A	P1POMOFO	-
	P2CKVLFC	-	-
	P3PRPELK	-	-

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
50	PB12050A	P1POMOFO	-
	PB12050B	P2POMOFO	-
	P3CKVLFC	-	-
51	PB12050A	P1POMOFO	-
	PB12050B	P2POMOFO	-
	PB12044C	P3POMOFO	-
52	PB12050A	P1POMOFO	-
	PB12050B	P2POMOFO	-
	P3PRPELK	-	-
53	PB12050A	P1POMOFO	-
	P2PRPELK	-	-
	P3CKVLFC	-	-
54	PB12050A	P1POMOFO	-
	P2PRPELK	-	-
	PB12044C	P3POMOFO	-
55	PB12050A	P1POMOFO	-
	P2PRPELK	-	-
	P3PRPELK	-	-
56	P1PRPELK	-	-
	P2CKVLFC	-	-
	PB12044C	P3POMOFO	-
57	P1PRPELK	-	-
	PB12050B	P2POMOFO	-
	P3CKVLFC	-	-
58	P1PRPELK	-	-
	PB12050B	P2POMOFO	-
	PB12044C	P3POMOFO	-
59	P1PRPELK	-	-
	PB12050B	P2POMOFO	-
	P3PRPELK	-	-

Table II.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
60	P1PRPELK	-	-
	P2PRPELK	-	-
	PB12044C	P3POMOFO	-
61	PB12041A	DHMUP1TO	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
62	PB12041B	DHMUP2TO	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
63	RGPIPARU	DHMUP1TO	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
64	RGPIPBRU	DHMUP2TO	-
	AFCSTTRU	-	-
	AFPWSTRU	-	-
65	PB12052B	CWPMP2FO	DHMUP2TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
66	PB12003B	CWCONBFO	DHMUP2TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
67	CWMUV1FC	RGCOLBFO	DHMUP2TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
68	CWMUV3FC	RGCOLBFO	DHMUP2TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
69	CWMUP2RU	RGCOLBFO	DHMUP2TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
70	PB12052A	CWPMP1FO	DHMUP1TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
71	PB12003A	CWCONAFO	DHMUP1TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
72	CWMUV1FC	RGCOLAFO	DHMUP1TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
73	CWMUV2FC	RGCOLAFO	DHMUP1TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
74	CWMUP1RU	RGCOLAFO	DHMUP1TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
75	SWCWTBRU	CWCONAFO	DHAHX1TO
			DHMUP1TO
		CWCONBFO	DHAHX2TO
			DHMUP2TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
76	SWCWTBRU	CWCONAFO	DHAHX1TO
			DHMUP1TO
		CWCONBFO	DHAHX2TO
			DHMUP2TO
	PB12TBDN	AFPWVATC	-
	AFCSSTRU	-	-
77	SWCWTBRU	CWCONAFO	DHAHX1TO
			DHMUP1TO
		CWCONBFO	DHAHX2TO
			DHMUP2TO
	PB12TBDM	AFCSVATC	-
	AFPWSTRU	-	-

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
78	SWCWTBRU	CWCONAFO	DHAHX1TO DHMUP1TO
		CWCONBFO	DHAHX2TO DHMUP2TO
	PB12TBDM	AFCSVATC	-
	PB12TBDN	AFPWVATC	-
79	SWCWTBRU	CWCONAFO	DHAHX1TO DHMUP1TO
		CWCONBFO	DHAHX2TO DHMUP2TO
	AFCSOVFC	SØDRUMNS	AFFWPAFO
	AFPWOVFC	SØDRUMNS	AFFWPAFO
80	SWECTARU	CWCONAFO	DHAHX1FO DHMUP1FO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
81	SWECTBRU	CWCONBFO	DHAHX2TO DHMUP2TO
	AFCSTTRU	-	-
	AFPWSTRU	-	-
82	AFTURBFO	-	-
	PB12060A	SWMUPAFO	AFFWPBFO DHAHX1TO
	PB12060B	SWMUPBFO	AFFWPCFO DHAHX2FO
83	AFTURBFO	-	-
	PB12060A	SWMUPAFO	AFFWPBFO DHAHX1FO
	PB12028B	SWPMPBFO	AFFWPCFO DHAHX2FO
84	AFTURBFO	-	-
	PB12028A	SWPMPAFO	AFFWPBFO DHAHX1FO
	PB12060B	SWMUPBFO	AFFWPCFO DHAHX2FO

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
85	AFTURBFO	-	-
	PB12028A	SWPMPAFO	AFFWPBFO
			DHAHX1FO
	PB12028B	SWPMPBFO	AFFWPCFO
			DHAHX2FO
86	AFTURBFO	-	-
	PB12052A	CWPMPAFO	AFFWPBFO
			DHAHX1FO
			DHMUP1FO
	PB12050B	CWAF1BFO	AFFWPCFO
			DHAHX2FO
87	AFTURBFO	-	-
	PB12052A	CWPMPAFO	AFFWPBFO
			DHMUP1FO
			DHAHX1FO
	PB12060B	SWMUPBFO	AFFWPCFO
			DHAHX2FO
88	AFTURBFO	-	-
	PB12052A	CWPMPAFO	AFFWPBFO
			DHMUP1FO
			DHAHX1FO
	PB12028B	SWPMPBFO	AFFWPCFO
			DHAHX2FO
89	AFTURBFO	-	-
	PB12003A	CWEVPAFO	DHAHX1FO
			AFFWPBFO
			DHMUP1FO
	PB12050B	CWAF1BFO	AFFWPCFO
			DHMUP2FO
90	AFTURBFO	-	-
	PB12003A	CWEVPAFO	AFFWPBFO
			DHAHX1FO
			DHMUP1FO
	PB12060B	CWMUPBFO	AFFWPCFO
			DHAHX2FO

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
91	AFTURBFO	-	-
	PB12003A	CWEVPAFO	AFFWPBFO
			DHAHX1FO
			DHMUP1FO
	PB12028B	SWPMPBFO	AFFWPCFO
			DHAHX2FO
92	AFTURBFO	-	-
	PB12050A	CWAF1AFO	AFFWPBFO
			DHAHX1FO
	PB12003B	CWEVPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
93	AFTURBFO	-	-
	PB12050A	CWAF1AFO	AFFWPBFO
			DHAHX1FO
	PB12003B	CWEVPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
94	AFTURBFO	-	-
	PB12028A	SWPMPAFO	AFFWPBFO
			DHAHX1FO
	PB12003B	CWEVPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
95	AFTURBFO	-	-
	PB12052A	CWPMPAFO	AFFWPBFO
			DHAHX1FO
			DHMUP1FO
	PB12003B	CWEVPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
96	AFTURBFO	-	-
	PB12003A	CWEVPAFO	AFFWPBFO
			DHAHX1FO
			DHMUP1FO
	PB12003B	CWEVPBFO	AFFWPCFO
			DHAHX1FO
			DHMUP1FO

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
97	AFTURBFO	-	-
	PB12050A	CWAF1AFO	AFFWPBFO
			DHAHX1FO
	PB12052B	CWPMPBFO	AFFWPCFO
			DHAHX1FO
			DHMUP1FO
98	AFTURBFO	-	-
	PB12060A	SWMUPAFO	AFFWPBFO
			DHAHX1FO
	PB12052B	CWPMPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
99	AFTURBFO	-	-
	PB12028A	SWPMPAFO	AFFWPBFO
			DHAHX1FO
	PB12052B	CWPMPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
100	AFTURBFO	-	-
	PB12052A	CWPMPAFO	AFFWPBFO
			DHAHX1FO
			DHMUP1FO
	PB12052B	CWPMPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
101	AFTURBFO	-	-
	PB12003A	CWEVPAFO	AFFWPBFO
			DHAHX1FO
			DHMUP1FO
	PB12052B	CWPMPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
102	AFTURBFO	-	-
	PB12052A	CWPMPAFO	AFFWPBFO
			DHAHX1FO
			DHMUP1FO
	CWAFV1FC	CWEVPBFO	AFFWPCFO

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
103	AFTURBFO	-	-
	PB12003A	CWEVPBFO	AFFWPBFO
			DHAHX1FO
			DHMUP1FO
	CWAFV2FC	CWEVPBFO	AFFWPCFO
104	AFTURBFO	-	-
	CWAFV6FC	CWEVPAFO	AFFWPBFO
	PB12052B	CWPMPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
105	AFTURBFO	-	-
	CWAFV7FC	CWEVPAFO	AFFWPBFO
	PB12052B	CWPMPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
106	AFTRUBFO	-	-
	CWAFV6FC	CWEVPAFO	AFFWPBFO
	PB12003B	CWEVPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
107	AFTURBFO	-	-
	CWAFV7FC	CWEVPAFO	AFFWPBFO
	PB12003B	CWEVPBFO	AFFWPCFO
			DHAHX2FO
			DHMUP2FO
108	AFFWPAFO	-	-
	PB12060A	SWMUPAFO	AFFWPBFO
			DHAHX1FO
	PB12060B	SWMUPBFO	AFFWPCFO
			DHAHX2FO
109	AFFWPAFO	-	-
	PB12060A	SWMUPZFO	AFFWOBFO
			DHAHX1FO
	PB12028B	SWPMPBFO	AFFWPCFO
			DHAHX2FO

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
110	AFFWPAFO	-	-
	PB12028A	SWPMPAFO	AFFWPBFO
			DHAHX1FO
	PB12060B	SWMUPBFO	AFFWPCFO
			DHAHX2FO
111	AFFWPAFO	-	-
	PB12028A	SWPMPAFO	AFFWPBFO
			DHAHX1FO
	PB12028B	SWPMPBFO	AFFWPCFO
			DHAHX2FO
112	AFFWPAFO	-	-
	PB12052A	CWPMPAFO	AFFWPBFO
			DHAHX1FO
			DHMUP1FO
	PB12050B	CHWF1BFO	AFFWPCFO
			DHAHX2FO
113	AFFWPAFO	-	-
	PB12052A	CWPMPAFO	AFFWPBFO
			DHMUP1FO
			DHAHX1FO
	PB12060B	SWMUPBFO	AFFWPCFO
			DHAHX2FO
114	AFFWPAFO	-	-
	PB12052A	CWPMPAFO	AFFWPBFO
			DHMUP1FO
			DHAHX1FO
	PB12028B	SWPMPBFO	AFFWPCFO
			DHAHX2FO
115	AFFWPAFO	-	-
	PB12003A	CWEVPAFO	DHAHX1FO
			AFFWPBFO
			DHMUP1FO
	PB12050B	CWAF1BFO	AFFWPCFO
			DHMUP2FO

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
116	AFFWPAF0	-	-
	PB12003A	CWEVPAF0	AFFWPBF0
			DHAHX1F0
			DHMUP1F0
	PB12060B	CWMUPBF0	AFFWPCF0
			DHAHX2F0
117	AFFWPAF0	-	-
	PB12003A	CWEVPAF0	AFFWPBF0
			DHAHX1F0
			DHMUP1F0
	PB12028B	SWPMPBF0	AFFWPCF0
			DHAHX2F0
118	AFFWPAF0	-	-
	PB12050A	CWAF1AF0	AFFWPBF0
			DHAHX1F0
	PB12003B	CWEVPBF0	AFFWPCF0
			EHAHX2F0
			DHMUP2F0
119	AFFWPAF0	-	-
	PB12050A	CWAF1AF0	AFFWPBF0
			DHAHX1F0
	PB12003B	CWEVPBF0	AFFWPCF0
			DHAHX2F0
			DHMUP2F0
120	AFFWPAF0	-	-
	PB12028A	SWPMPAF0	AFFWPBF0
			DHAHX1F0
	PB12003B	CWEVPBF0	AFFWPCF0
			DHAHX2F0
			DHMUP2F0
121	AFFWPAF0	-	-
	PB12052A	CWPMPAF0	AFFWPBF0
			DHAHX1F0
			DHMUP1F0
	PB12003B	CWEVPBF0	AFFWPCF0
			DHAHX2F0
			DHMUP2F0

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
122	AFFWPAFO PB12003A	$\overline{\text{CWEVPAFO}}$	$\overline{\text{AFFWPBFO}}$ DHAHX1FO DHMUP1FO
	PB12003B	CWEVPBFO	AFFWPCFO DHAHX2FO DHMUP2FO
123	AFFWPAFO PB12050A	$\overline{\text{CWAF1AFO}}$	$\overline{\text{AFFWPBFO}}$ DHAHX1FO
	PB12052B	CWPMPBFO	AFFWPCFO DHAHX2FO DHMUP2FO
124	AFFWPAFO PB12060A	$\overline{\text{SWMUPAFO}}$	$\overline{\text{AFFWPBFO}}$ DHAHX1FO
	PB12052B	CWPMPBFO	AFFWPCFO DHAHX2FO DHMUP2FO
125	AFFWPAFO PB12028A	$\overline{\text{SWPMPAFO}}$	$\overline{\text{AFFWPBFO}}$ DHAHX1FO
	PB12052B	CWPMPBFO	AFFWPCFO DHAHX2FO DHMUP2FO
126	AFFWPAFO PB12052A	$\overline{\text{CWPMPAFO}}$	$\overline{\text{AFFWPBFO}}$ DHAHX1FO DHMUP1FO
	PB12052B	CWPMPBFO	AFFWPCRO DHAHX2FO DHMUP2FO
127	AFFWPAFO PB12003A	$\overline{\text{CWEVPAFO}}$	$\overline{\text{AFFWPBFO}}$ DHAHX1FO DHMUP1FO
	PB12052B	CWPMPBFO	AFFWPCFO DHAHX2FO DHMUP2FO

Table H.1 (continued)

MINIMAL CUT SET NUMBER	COMPONENT FAILURE	PROVIDES SUPPORT TO	PROVIDES SUPPORT TO
128	AFFWPAF0	-	-
	PB12052A	CWPMPAF0	AFFWPBF0
			DHAHX1F0
			DHMUP1F0
	CWAFV1FC	CWEVPBF0	AFFWPCF0
129	AFFWPAF0	-	-
	PB12003A	CWEVPBF0	AFFWPBF0
			DHAHX1F0
			DHMUP1F0
	CWAFV2FC	CWEVPBF0	AFFWPCF0
130	AFFWPAF0	-	-
	CWAFV6FC	CWEVPAF0	AFFWPBF0
	PB12052B	CWPMPBF0	AFFWPCF0
			DHAHX2F0
			DHMUP2F0
131	AFFWPAF0	-	-
	CWAFV7F0	CWPMPBF0	AFFWPBF0
	PB12052B	CWPMPBF0	AFFWPCF0
			DHAHX2F0
			DHMUP2F0
132	AFFWPAF0	-	-
	CWAFV6FC	CWEVPAF0	AFFWPBF0
	PB12003B	CWEVPBF0	AFFWPCF0
			DHAHX2F0
			DHMUP2F0
133	AFFWPAF0	-	-
	CWAFV7FC	CWEVPAF0	AFFWPBF0
	PB12003B	CWEVPBF0	AFFWPCF0
			DHAHX2F0
			DHMUP2F0

APPENDIX I

CRBRP SHUTDOWN HEAT REMOVAL SYSTEM FAILURE DATA

CRBRP SHUTDOWN HEAT REMOVAL SYSTEM FAILURE DATA

The failure data for the basic events that appeared in the minimal cut sets used in this analysis is presented in Table I-1. The source of this data is WASH-1400. The pipe rupture data was modified since the sodium piping in the CRBRP is under low pressure and the data in WASH-1400 is for high pressure piping systems.

Table I.1 Basic event failure data

BASIC EVENT	FAILURE RATE (hr^{-1})
PSRGVSRU	1×10^{-11}
PSRXVSRU	1×10^{-12}
P1CKVLFC	1×10^{-7}
P2CKVLFC	1×10^{-7}
P3CKVLFC	1×10^{-7}
P1POMOFO	3×10^{-6}
P2POMOFO	3×10^{-6}
P3POMOFO	3×10^{-6}
P1PRPELK	2×10^{-10}
P2PRPELK	2×10^{-10}
P3PRPELK	2×10^{-10}
DHCTSVNC	1×10^{-8}
AFCSTTRU	1×10^{-10}
AFPWSTRU	1×10^{-10}
DHOHIVFC	1×10^{-7}
DHOHBVFC	1×10^{-7}
DHRLVLFC	1×10^{-7}
DHCKVLFC	1×10^{-7}
DHOFVSRU	1×10^{-10}
DHPRPELK	5×10^{-10}

Table I.1 (continued)

BASIC EVENT	FAILURE RATE (hr^{-1})
DHOHXTBL	1×10^{-8}
DHAHCPRU	2×10^{-11}
DHMUP1TO	3×10^{-5}
DHMUP2TO	3×10^{-5}
PB12041A	3×10^{-3}
PB12041B	3×10^{-3}
RGPIPARU	5×10^{-10}
RGPIPBRU	5×10^{-10}
PB12044C	3×10^{-3}
PB12050A	3×10^{-3}
PB12050B	3×10^{-3}
PB12052A	3×10^{-3}
PB12052B	3×10^{-3}
PB12003A	3×10^{-3}
PB12003B	3×10^{-3}
IGRSSPRU	5×10^{-10}
IGRSBPRU	5×10^{-10}
SWCWTBRU	1×10^{-11}
PB12TBDN	3×10^{-3}
PB12TBDM	3×10^{-3}

Table I.1 (continued)

BASIC EVENT	FAILURE RATE (hr^{-1})
AFPWOVFC	3×10^{-7}
AFCSOVFC	3×10^{-7}
SWCTTARU	1×10^{-10}
SWCTTBRU	1×10^{-10}
AFTRUBFO	3×10^{-6}
PB12060A	3×10^{-3}
PB12060B	3×10^{-3}
PB12028A	3×10^{-3}
PB12028B	3×10^{-3}
CWAFP0FC	3×10^{-7}
AFFWPBFO	1×10^{-5}
AFFWPCFO	1×10^{-5}

APPENDIX J

QUANTITATIVE RESULTS OF THE

CRBRP SHUTDOWN HEAT REMOVAL SYSTEM ANALYSIS

QUANTITATIVE RESULTS OF THE CRBRP SHUTDOWN HEAT REMOVAL SYSTEM ANALYSIS

The results of the quantitative analysis are presented in graphical form. Figures J.1 through J.12 present the unavailability importance of the most important basic events versus time.

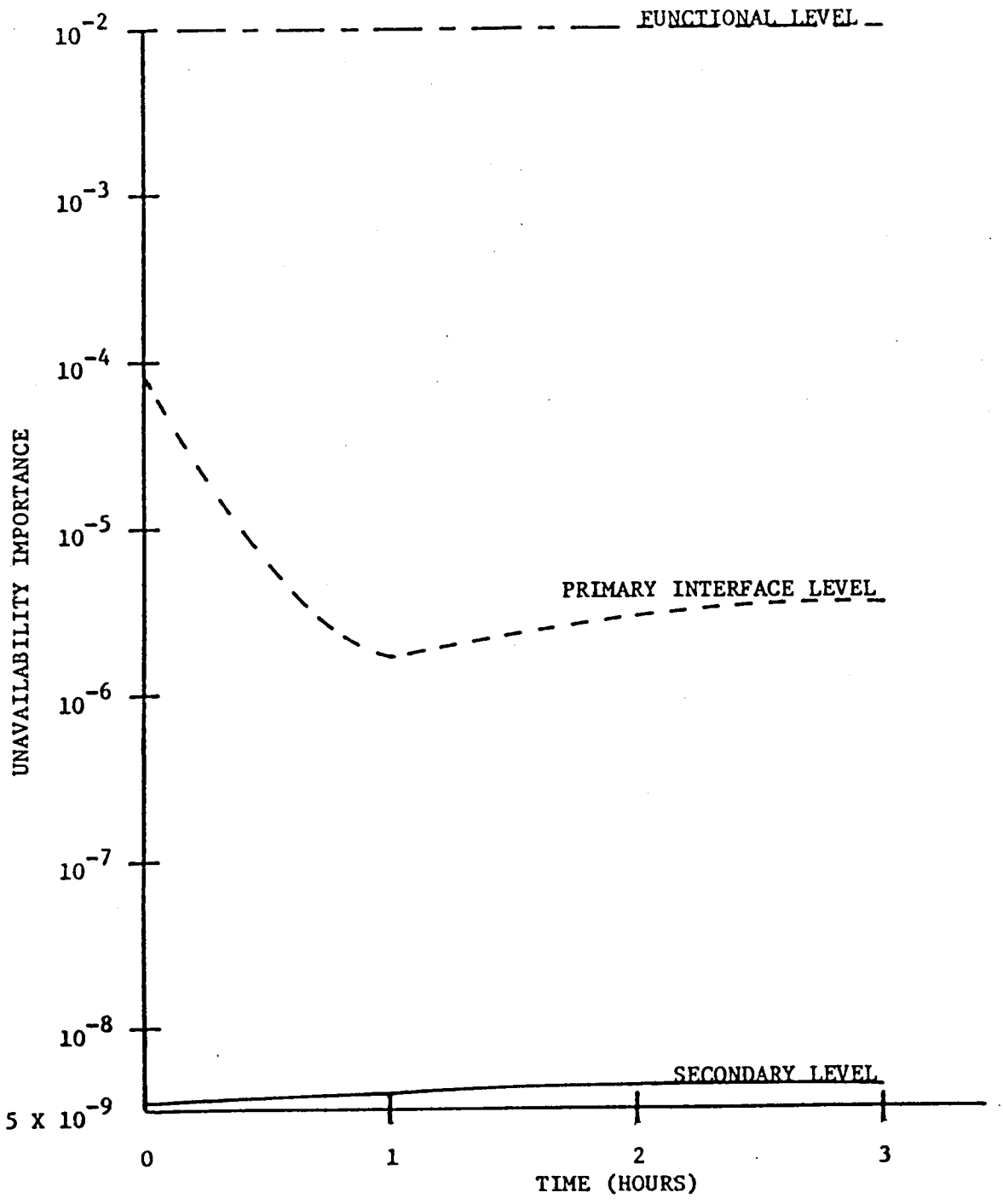

Figure J.1. Unavailability importance of primary loop 1, primary loop 2, and primary loop 3 pony motors for the functional, primary, and secondary interface levels.

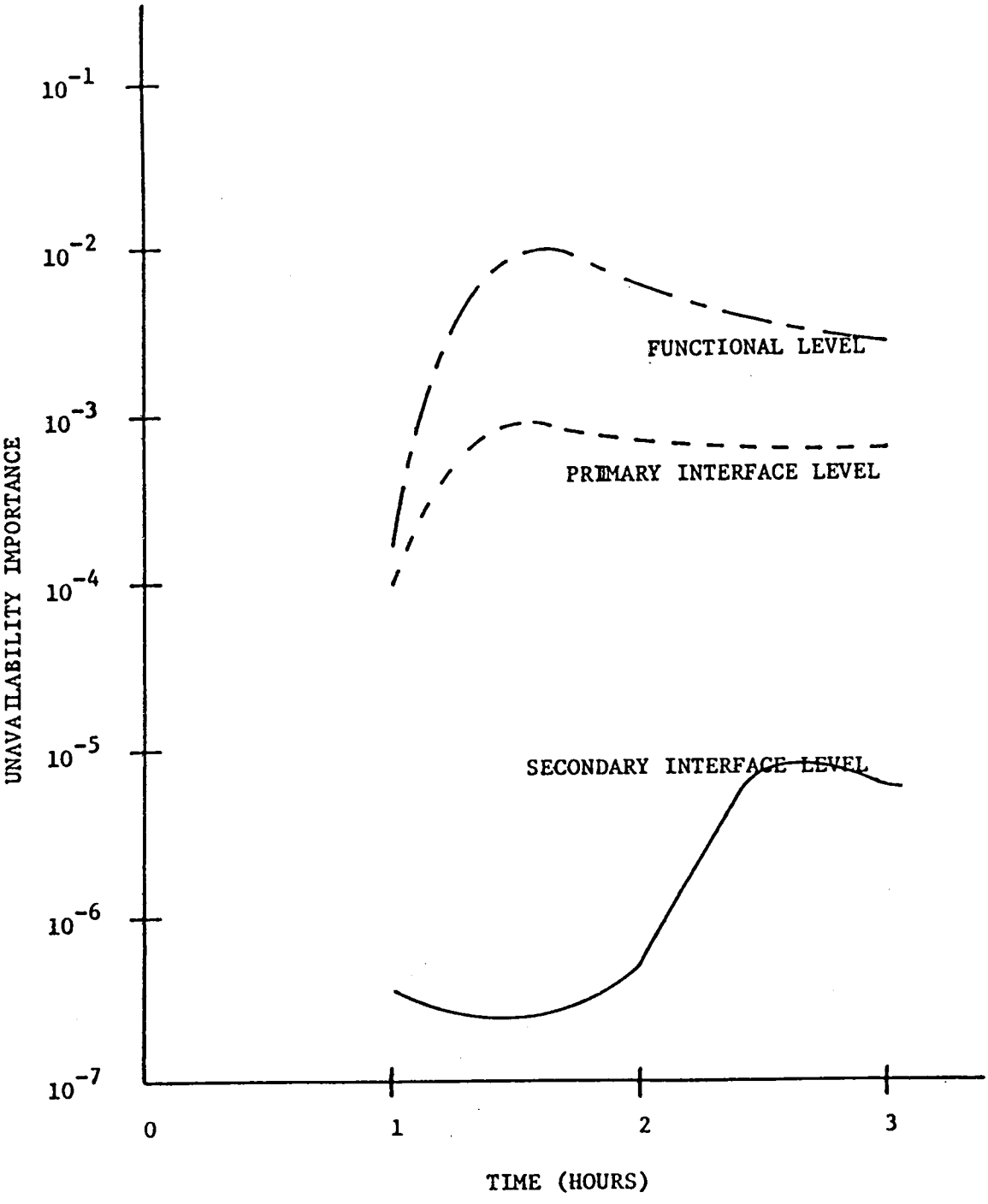

Figure J.2. Unavailability importance of primary loop 3 check valve on return to reactor for the functional, primary, and secondary interface levels.

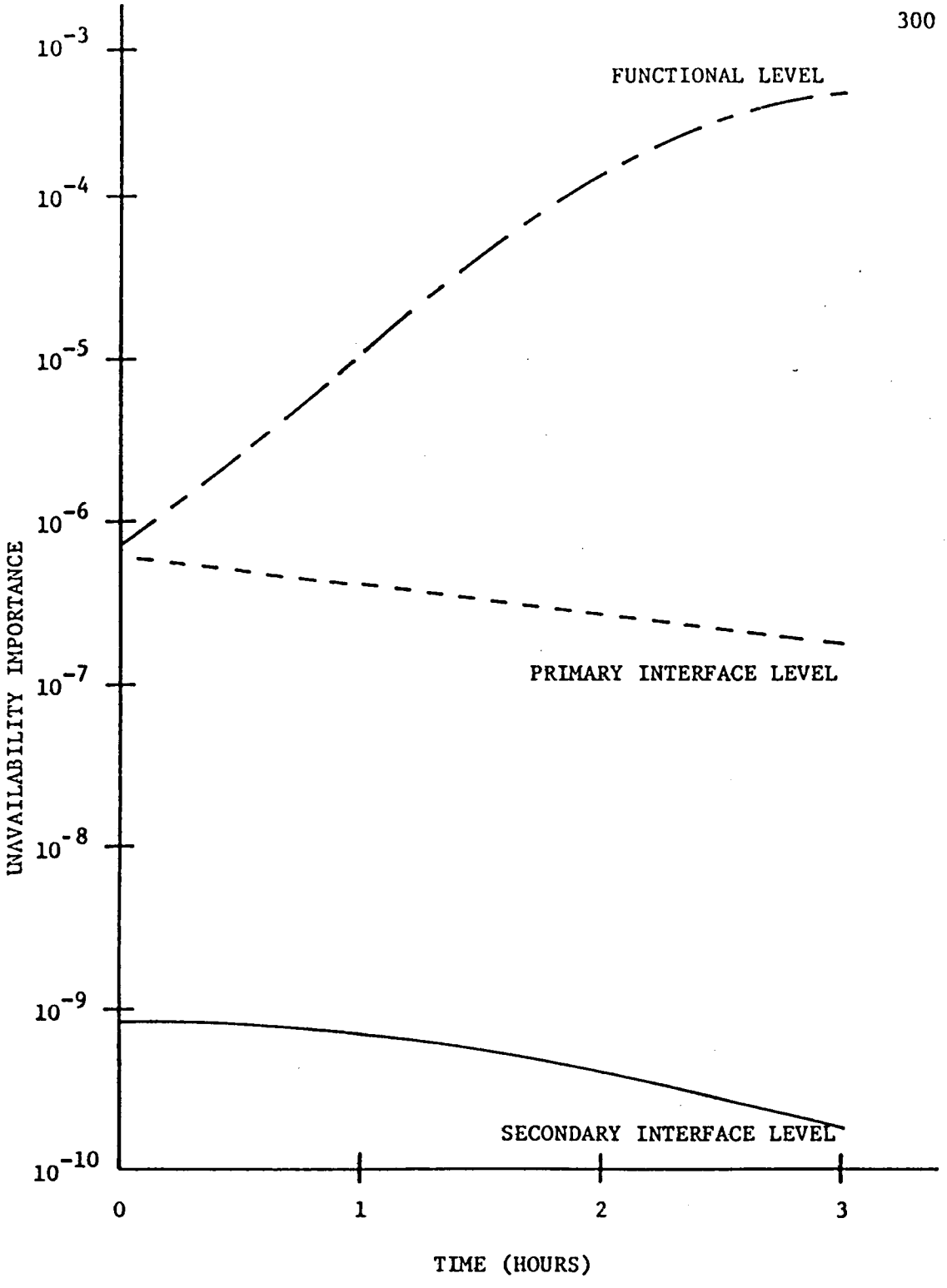

Figure J.3. Unavailability importance of primary loop 1 and primary loop 2 check valve on return to reactor for the functional, primary and secondary interface levels.

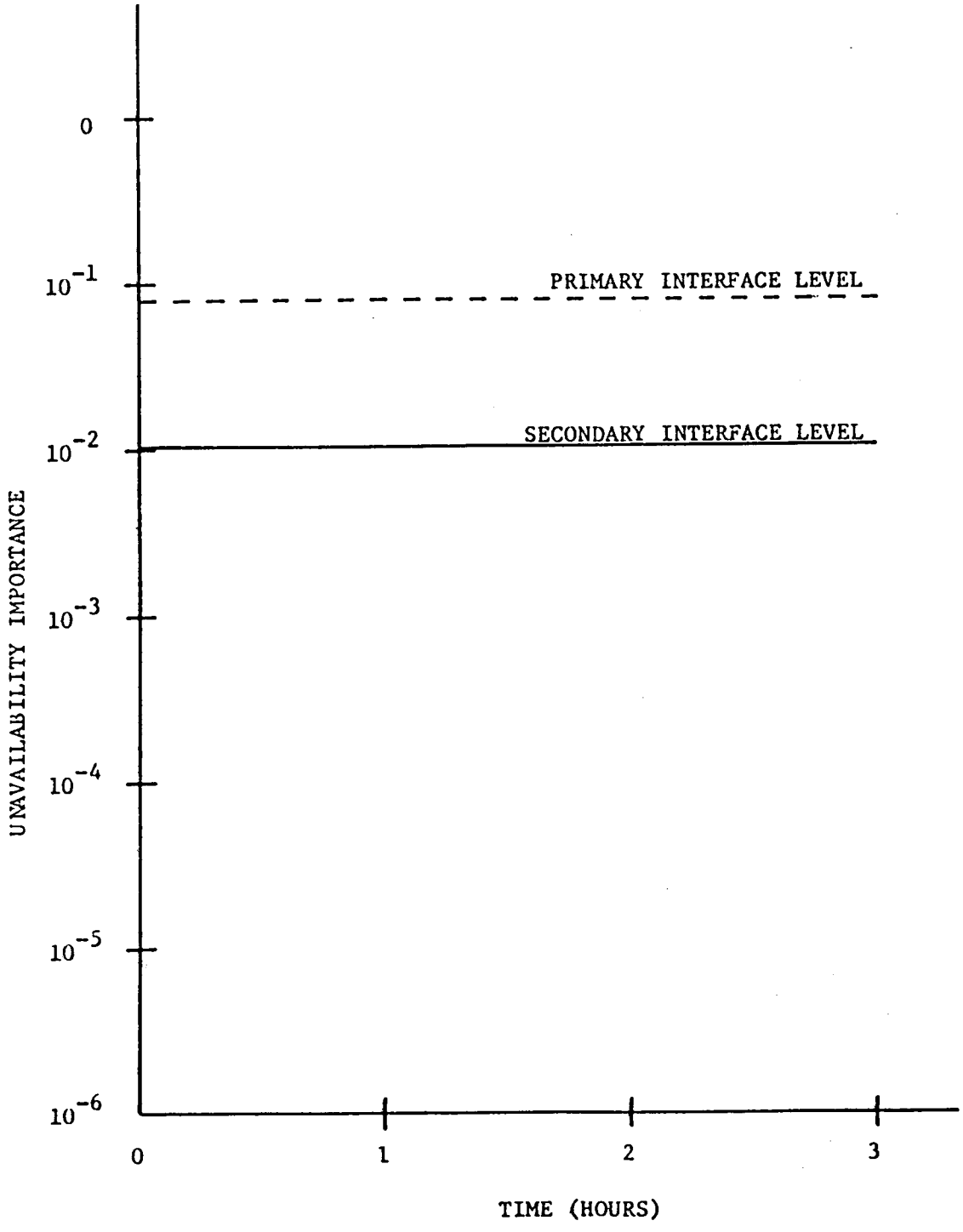

Figure J.4. Unavailability importance of power buses 12NIE050A and 12NIE050B for the primary and secondary interface levels.

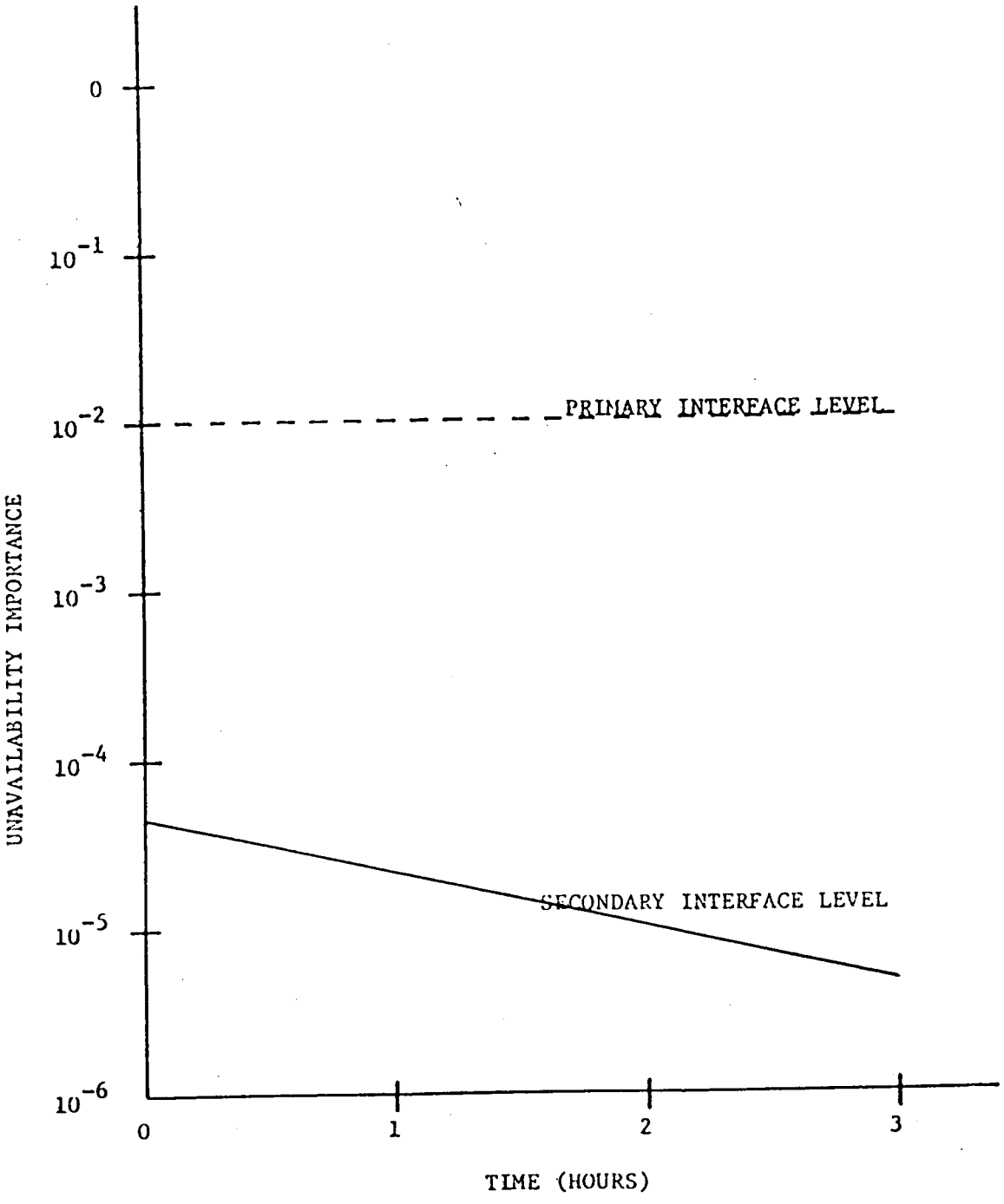

Figure J.5. Unavailability importance of power bus 12NIE044C for the primary and secondary interface levels.

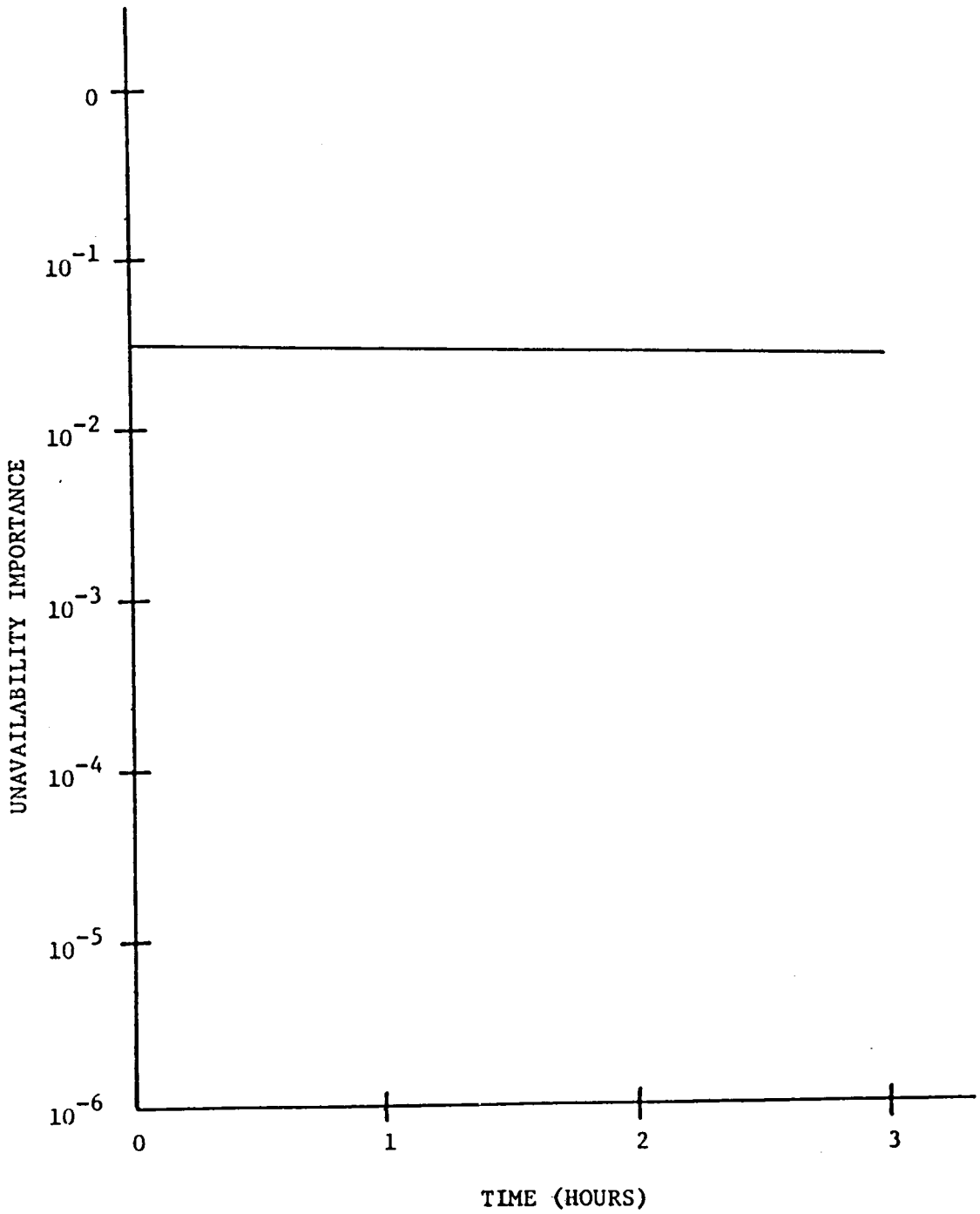

Figure J.6. Unavailability importance of power buses 12NIE003A and 12NIE052A at the secondary interface level.

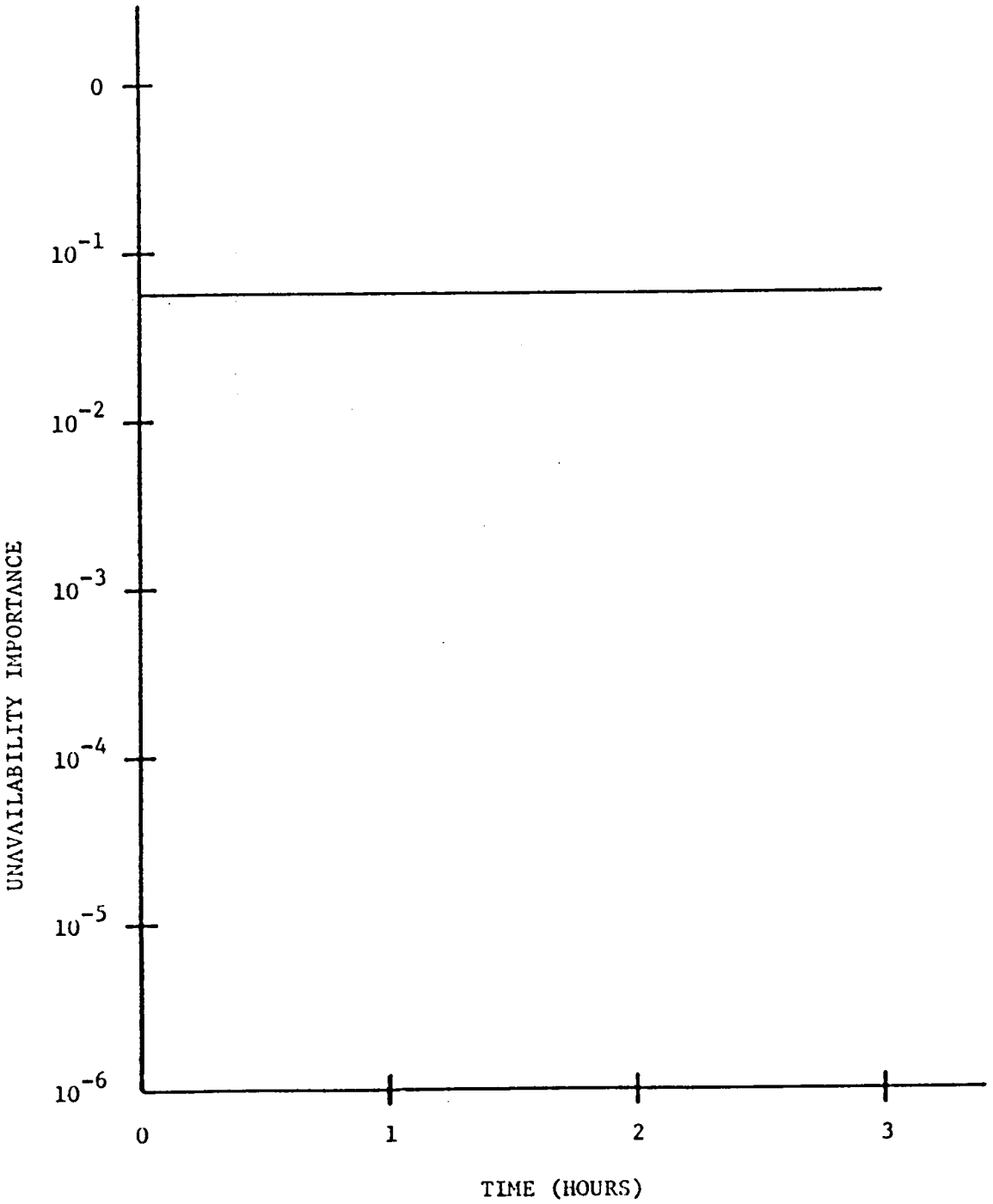

Figure J.7. Unavailability importance of power buses 12NIE003B and 12NIE052B at the secondary interface level.

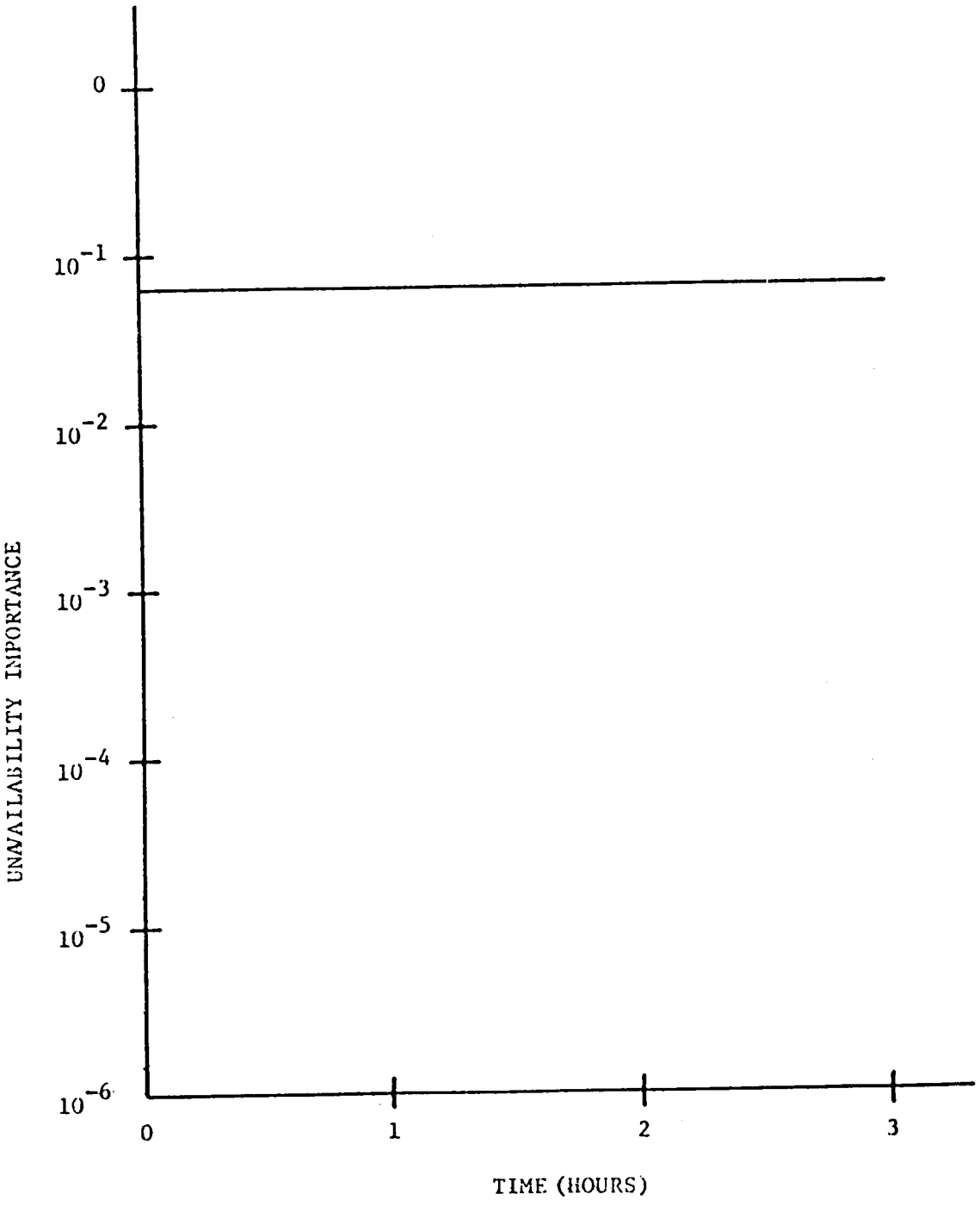

Figure J.8. Unavailability importance of power bus 12NIE060A at the secondary interface level.

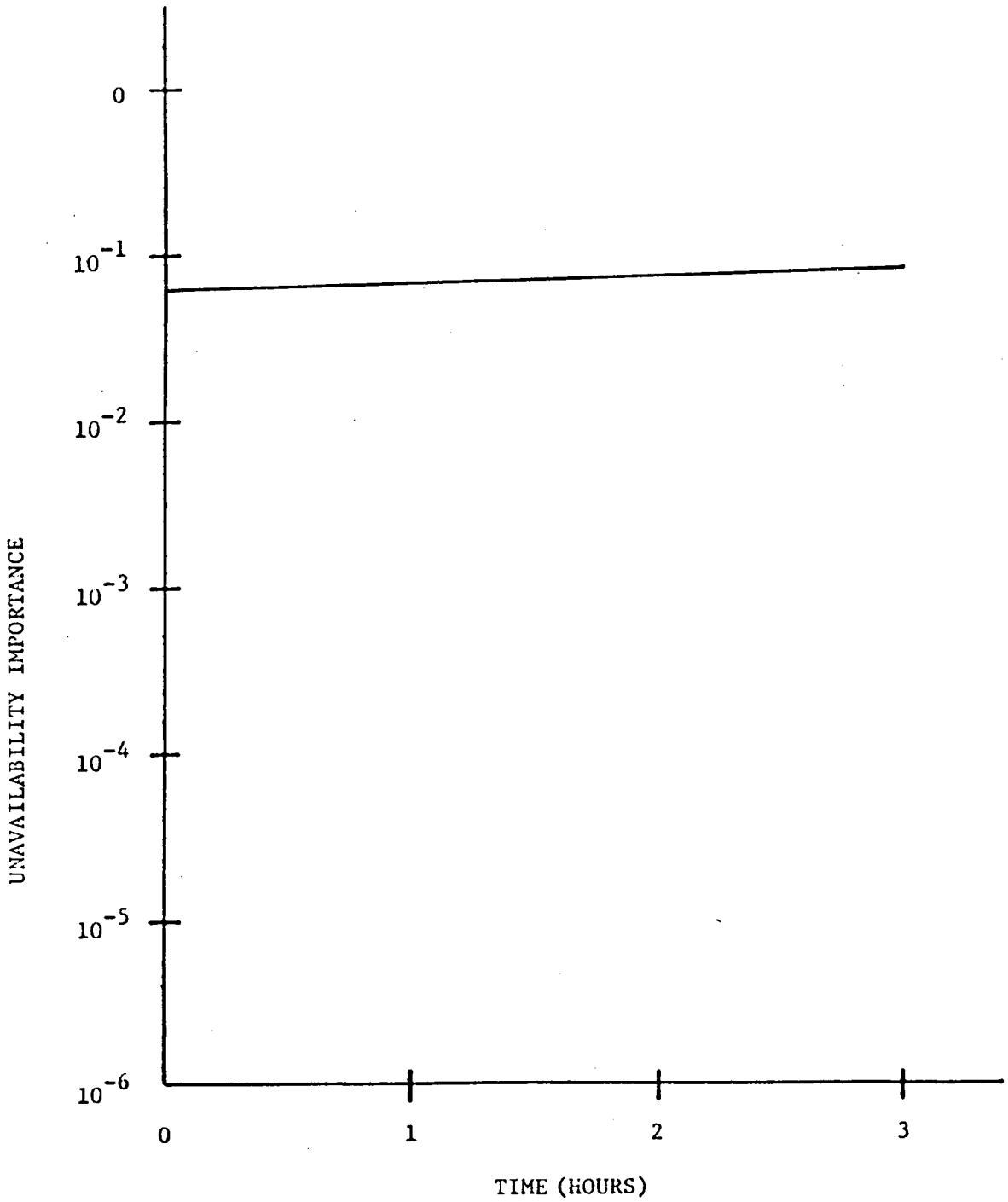

Figure J.9. Unavailability importance of power buses 12NIE028B and 12NIE060B at the secondary interface level.

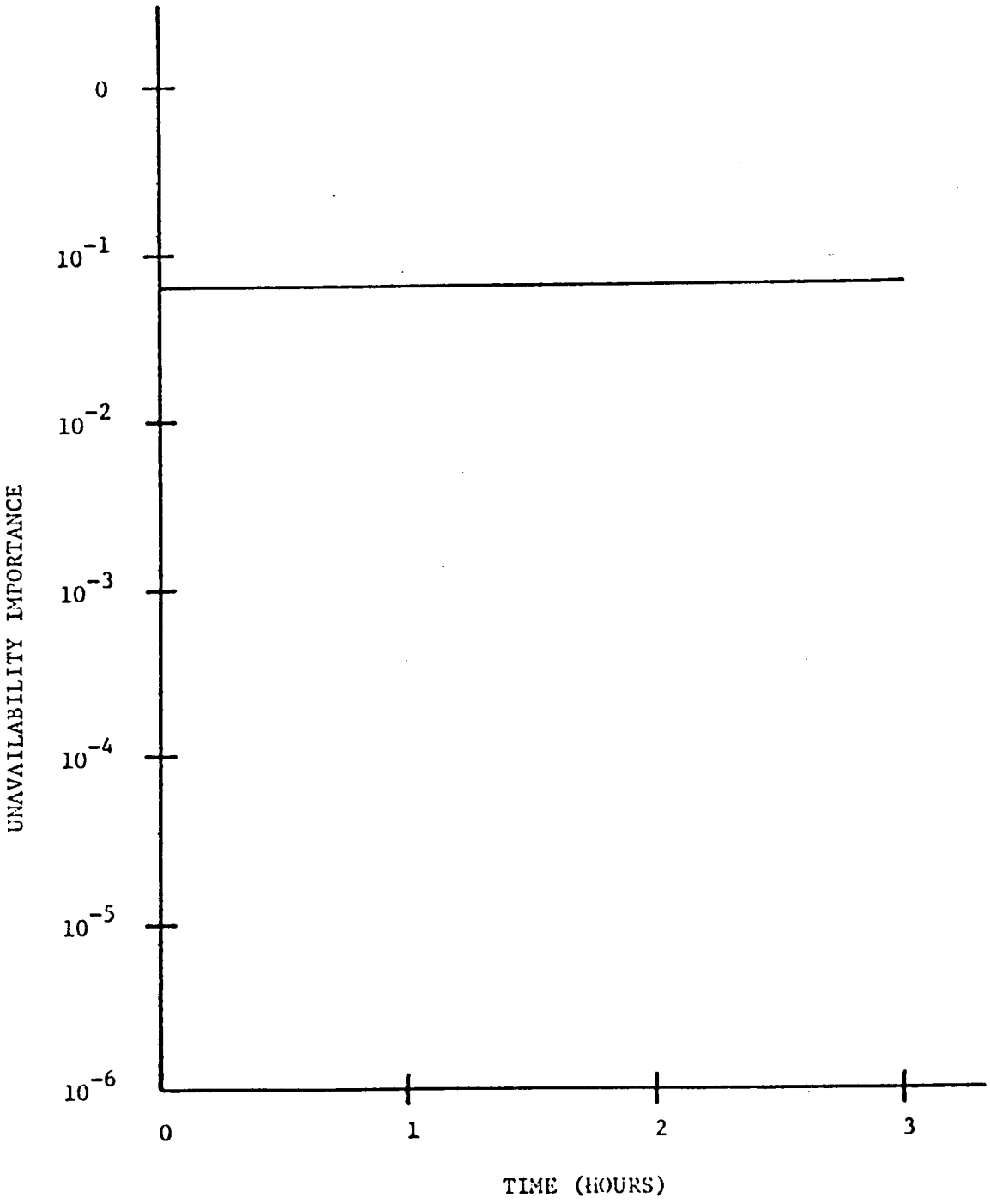

Figure J.10. Unavailability importance of power bus 12NIE028A at the secondary interface level.

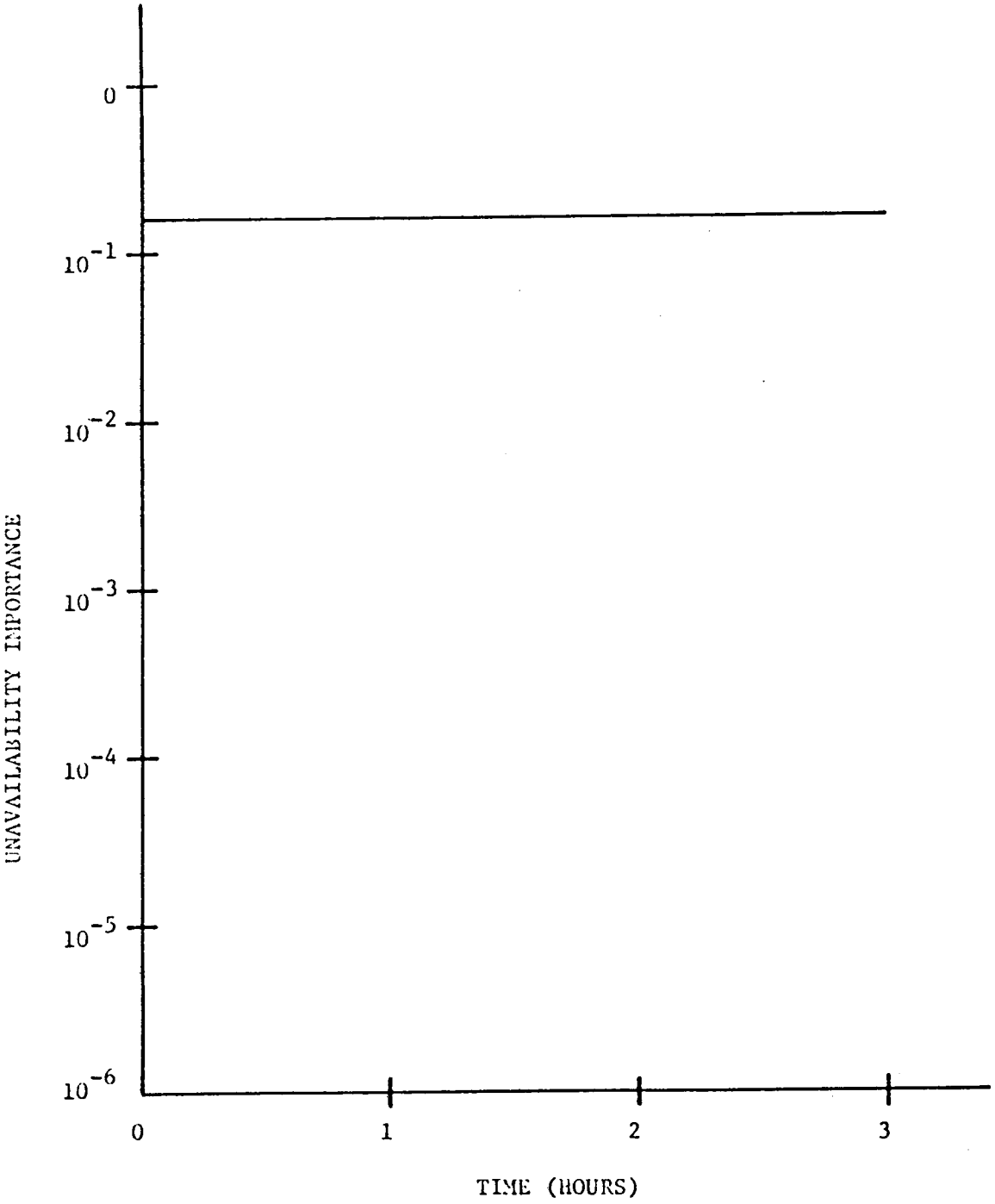

Figure J.11. Unavailability importance of the auxiliary feedwater pump turbine drive at the secondary interface level.

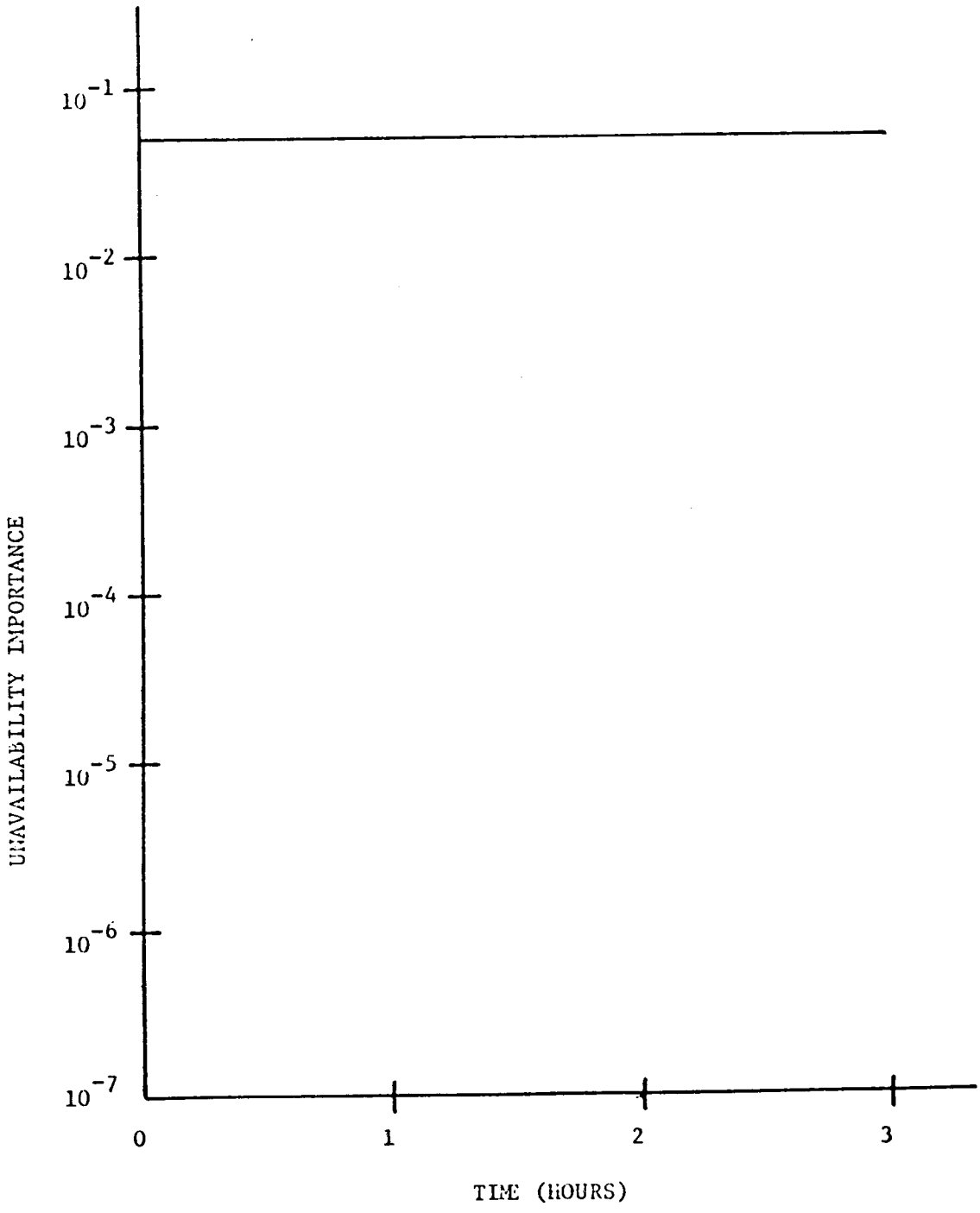

Figure J.12. Unavailability importance of the turbine driven auxiliary feedwater pump at the secondary interface level.

VITA

Michael David Muhlheim was born in Cleveland, Ohio on July 20, 1957. He is the son of Mr. and Mrs. Wayne R. Muhlheim. He was raised in Elyria, Ohio. After graduating from Elyria High School in June 1975, Michael entered the College of Engineering at The University of Tennessee, Knoxville. He was awarded a Bachelor of Science degree with a major in Nuclear Engineering in June 1980.

After receiving the Master of Science degree in March 1984, Michael will begin work pursuing a Doctor of Philosophy degree in the field of reliability and risk assessment. Michael is currently employed as a nuclear engineer at JBF Associates, Inc. working in the field of nuclear systems reliability and risk assessment.