

Radiological Assay of Burrowing Animals-Senior Design Project

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INTRODUCTION

The East Tennessee area hosts a diverse ecosystem including many burrowing animals of varying sizes from chipmunks to groundhogs [1]. After decades of legacy material buildup in and around locations along the Oak Ridge Reservation (ORR), radionuclides are contaminating these burrowing animals both externally and internally. To protect clean animals from contaminated areas, Oak Ridge National Laboratory (ORNL) wishes to relocate animals under a threshold of 50 dpm/cm² to safer locations [2]. The current operating procedure involves trapping these small animals in commercial cages by Wildlife Services to then be delivered to the Radiological Control Field Office [3]. There, handheld detectors are used to measure the animal's overall activity [2]. This method is inconsistent due to the variable size of the animals in relation to the cage as well as the inability to keep animals being measured still for long durations leading to unreliable, inconsistent measurements [2]. This poses a problem since data collection could be valuable for seeing contamination trends within specific areas of the ORR campus. Additionally, the varying animal sizes around the area makes it so some animals have more room than others to move around the trap skewing the measurement. This problem led to the formation of the Radiological Assay of Burrowing Animals (ABA) project to design a detection system to resolve these issues. The functionality of the detection system must limit the movement of the animal by making the dimensions of the system adjustable while the detection system aspect must be able to gather a proficient reading on the animal. The proposed design will utilize a Polyvinyl Toluene (PVT C₉H₁₀) scintillator array and adjustable chute to minimize animal movement while providing accurate gross count data.

MOTIVATION

Despite the restricted access designations on ORR, surrounding wildlife still roam the premises freely. If animals are allowed to roam between contaminated and clean areas, ORNL will have reduced control over the spread of contamination. To limit this, animals are passively monitored by catching them in commercial cat cages at different locations around the reservation and measuring their radioactivity [2]. This is done by a technician with a hand detector positioned around the cage at the technician's discretion [2]. This leaves the process open to technician

error and is also inefficient since the detector cannot get close to the animal, which is presumably moving throughout the cage [2]. The proposed detection system and accompanying resources will help standardize the process while also increasing accuracy to reduce the probability of a false negative. In addition to the detection system, the application and technician guide will help faculty at the Radiological Control Field Office monitor trends in captured animals for future work.

METHODOLOGY

To satisfy the need of ORNL, CAD modeling, application development, and MCNP modeling were used to develop and evaluate a potential detection system to measure the activity of small burrowing animals. Each part serves to illustrate the design, assist technicians in understanding trends in data, inform operators about the animals being surveyed, or to determine important detection characteristics that would otherwise require a physical prototype. The combination of these things will allow ORNL to effectively monitor the wildlife population present on ORR and potentially prevent further harm to the ecosystem encompassed.

CAD Design

The preliminary designs for the detection system followed the same principles as a cattle chute. This being a narrow chute with adjustable walls to squeeze and hold a cow into place. The initial design concept can be seen below in Figure 1.

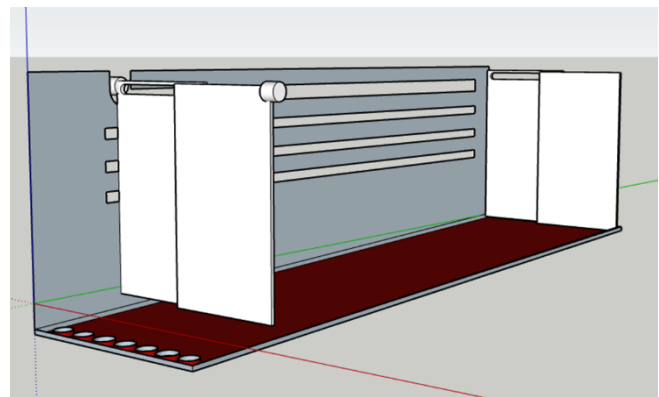


Fig 1. Original system design based on cattle chute concept.

This design, in addition to adjustable walls, also proposed ways to adjust the length and the height to better suit the variability of the animals that would be measured. This base design was then scaled to an appropriate size based on the largest animal that could be captured in a commercial cat cage, a gopher, and some aspects were simplified to produce a cleaner design. The average size of a gopher was determined and then rounded up to ensure that the system was big enough for any animals that might be measured. The maximum size inside of the system was made to be 36" long, 24" tall, and 18" wide. The outside view of the system can be seen below in Figure 2.

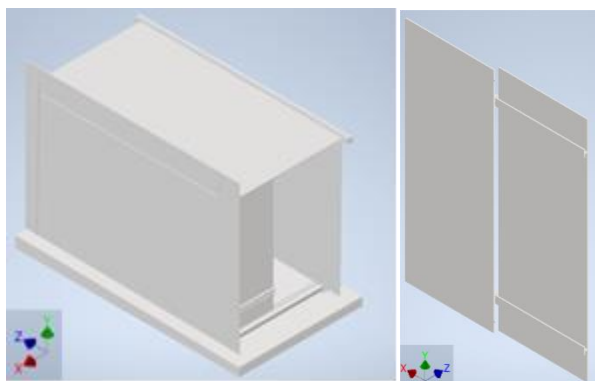


Fig 2. Outside view and sliding door mechanism in CAD

The original design had two sliding doors to adjust the width while the final one has only one sliding door to minimize mechanical failure. To assist with adjusting the length and width, a moving wall was added. This can be seen in the foreground of the figure and has two channels cut out of it. The vertical channel allows the width to be reduced as the moving wall can slide along the back wall. The horizontal channel is a rail in which the doors will be connected. This rail will allow the collapsible door to be adjusted to create a specific length. The roof is based off a garage door as it can roll up as the width is reduced. The roof is also connected to the moving wall and has a handle attached so that the wall can be moved with minimal danger to the technician. The other two walls are stationary and sit firmly connected to the base to support the rest of the system. Finally, the base was given 2" of extra space so that a scale for weighing the animals can be easily placed below. The base was also made with features to assist the rest of the design. First the base was made at an angle and had holes added that go all the way through so that any urine or fluids that the animal might excrete during the measurement would not accumulate in the system. The second feature is the channel cut out of it so that the moving wall may be further anchored into place. The CAD design has been 3D printed at a 20% scale to act as a proof of concept for its mechanical operation.

The detector associated with this system will be an array of six PVT plastic scintillators that line the entirety of the long walls on each side of the system. The thought is that no matter where the animal moves in the space it has provided,

there will be a detector near enough to measure any contamination. The set up of detectors and their efficiency is determined via MCNP modeling, discussed below.

App Development

The ABA Log application was designed to be a user-friendly way for ORNL radiation safety technicians to save and view data on collected animals. It is useful for observing long-term trends in contaminated animals on the ORR. Google's Android operating system (OS) was chosen for accessibility reasons: it is relatively easy to develop and publish an app on this OS, and, as the most widely used mobile operating system worldwide, an Android app can be easily downloaded and used by most people and organizations [4]. The Android Studio integrated development environment (IDE) and the Java language were chosen for the numerous advantages of each. Android Studio is Google's official IDE for Android apps, and has many tools specifically designed for the creation of touch screen applications such as a visual design editor for creating the user interface. The IDE offers many coding languages for development including C++, Java, and Kotlin. Java was chosen because it is beginner-friendly, well documented, and uses object-oriented programming (OOP). OOP simplifies coding by using self-contained code structures, called objects, which can be reused for multiple purposes or modified without affecting the rest of the code.

After deciding which OS, IDE, and programming language to use, the next step was deciding the necessary features and how the user should interact with the app. As stated above, the app is a tool for technicians to save and view data on trapped animals, with a focus on simplicity. The first feature that was implemented is a home screen, which can be seen in figure 3. The home screen greets the user with the app title and touch buttons which the user can interact with to be directed to the desired page. The visual design editor offers an easy way to drag and drop desired design elements onto the UI layout screen. The code for the home screen only includes logic for listening for a 'click' on a button and directing the user to the associated page.

The next feature to be designed was the 'new entry' page, also shown in figure 3. On this page, the user interacts with text fields to enter recorded data on trapped animals, as well as a save button or a home button. Again, the UI elements were created, followed by associated code. Data entry fields include animal species, measured activity and mass, additional notes on the animal's condition, and capture location and date. In this version of the app, each of these fields is manually filled. Upon selecting the save button, each data field is saved in a single string, which can be read by the

data viewing pages, and the user is directed to the ‘history log’ page.

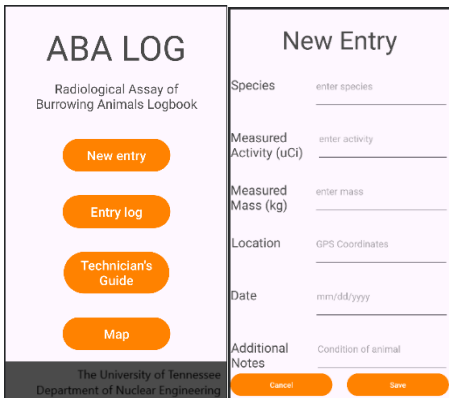


Fig 3. Home page and new entry page on the ABA Log app

The history log page provides one of the two ways for viewing saved data. The layout of this page includes page title, a list view of all entries, and a home button. Each time this page is loaded, the app checks for new entries to ensure that data is always up to date. The list view shows all recorded information in order from newest to oldest. The map feature was the last required feature. It provides a visual way to view concentrations of contaminated animals in controlled areas. The layout includes a title, a home button, and a static satellite image view of the ORR campus, where a pin can be plotted on the animal capture location. A static image was chosen to include the area of interest for prototype purposes. The GPS coordinates saved in the animal entry page are converted into (x, y) coordinates to be plotted onto a grid. The origin of the grid is the reference point, with known GPS values saved at the origin point. The (x, y) coordinates are calculated by taking the difference each in latitude and longitude and the origin, and a pin is plotted on that point.

App testing was done first using an Android emulator built into the Android Studio IDE. Testing was done often, mostly after major changes were made to the code. It is also important to test on a physical device, so the app was also loaded onto a personal Android device to confirm usability. Physical device testing was mostly done in the later stages of development because of the added complications of connecting a device via USB to the development computer and downloading the app to the device.

Technicians Guide

To ensure the safety of both the workers using the detection system and the animal, a technician guide was created. This guide aims to lay out clear instructions on how the detection system must be set up and how a measurement should be performed. The technician must place the detection

system in the widest and longest configuration, and then take a 10-minute background activity count to subtract from the measurement recorded on the animal. Once an animal is inside, the technician can use the single channel analyzer on the top of the detection system to take a 1-minute activity count. In addition to the activity value, the scale at the bottom of the detection system will be used to take a mass measurement in grams. Once the measurement is taken the door to the detection system is opened to allow the animal to leave if below the 100 dps/cm² threshold to be relocated to a clean environment. The Hazards, Safety, and Warnings section was created to give notices and regulations compiled on proper handling and potential biological hazards associated with native animals to the ORR [5]. The project's primary hazards come from the mechanical aspect of the detection system or the animals themselves. The detection system uses moving parts to hold and release the animal and resize the system. These moving parts create a mechanical pinching hazard on top of the risk of bites or scratches from an animal. To ease this hazard, it is advised that the technician use gloves, proper training, and utilize the animal information section of the technician guide to understand the aggression level of an animal before interacting with it. Furthermore, hazard information on known relevant radionuclides at ORR, like cesium 137, was added as a quick reference for technicians [6]. Lastly, anatomical data of common East Tennessee wildlife was also compiled to illustrate potential areas for radionuclide buildup in addition to increasing the fidelity of MCNP phantom modeling discussed in the following section [7]. An example of a complete technician guide can be seen in Figure 4.

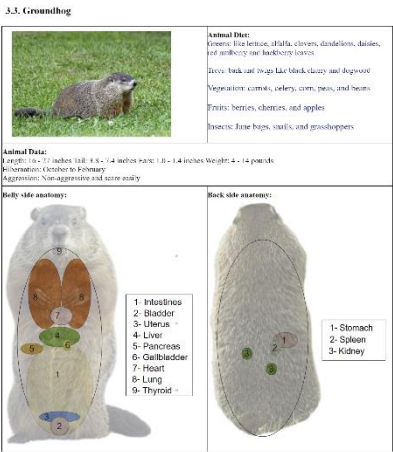


Fig 4. Animal information section of technician guidebook

The information includes estimated size ranges, so the technician can gauge the detection system's alignment for a good activity measurement and animal comfort. Additionally, behavioral habits are provided so that the technician can use an extra level of caution if an animal is

aggressive or will move and thrash around inside the detection system. Dietary information is also provided to help distinguish isotope pathways to the body in case a particular group of animals with a similar diet are consuming large quantities of contamination from a similar food source. Lastly, a picture of the animal is given if a technician is unaware of what it looks like and to help identify it. In addition to a picture of the animal in their natural habitat, two anatomical diagrams are provided of each animal. One picture is of the dorsal side while the other is of the posterior.

MCNP Modeling

It is important to understand the detection efficiency of the proposed design to ensure that measurements taken are accurate. Without a calibrated source and a physical prototype of the detector, it is impossible to assess the real-world efficiency of the detector. However, MCNP can be used in place of these things to produce the geometric, the proportion of radiation from a source that crosses the plane of the detector, and photon interaction efficiency, the number of photons counted by the detector for a given source activity.

MCNP is a high-fidelity radiation transport software that can be used for several purposes from estimating radiation intensity through shielding to estimating the efficiency of a detector [7]. In this work, small animal phantoms native to the Oak Ridge Reservation were modeled as they would appear during a measurement of their radioactivity. A general quadrupedal mammal, gopher, and quadrupedal reptile, box turtle, were selected to represent their larger taxonomical groups due to their similarities with many of their constituents. Using the anatomical data found in the technician's guide and the detection system's specifications laid out in CAD, several phantoms with widths ranging from 30 cm to 20 cm were added into an appropriately sized model of the detection system[8,9]. The general shape was made for each phantom; then, organs were added to the relative location displayed in the technician guide. For the mammals it was assumed that the animals body was adipose tissue whereas its organs were assumed to be muscle tissue. Some organs, like the lungs and ovaries, had specific tissue types listed in the PNNL compendium for materials which were used instead [10]. For the turtle phantom similar assumptions were made for the internal tissues of the animal, except the turtle's shell was assumed to be a mixture of keratin and bone [8,10]. Lastly, skeletal structures were simplified to represent the most substantial components i.e., spine, hips, and legs. Examples of the animal phantoms are shown below in Figure 5.

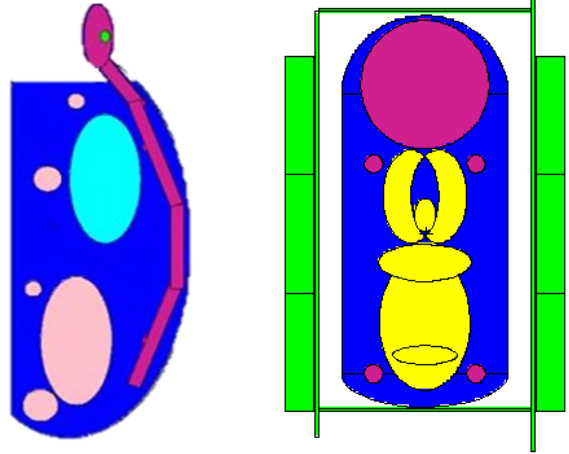


Fig 5. Example of animal phantoms used in MCNP modeling

The PVT (C_9H_{10}) scintillator array was then created by making a 3x2 array of 5x5 inch photomultiplier tubes (PMTs) coupled with small PVT parallelepipeds one cm smaller in length and width with a 5 mm thickness. It was assumed that aluminum was a sufficient analog for a PMT in regard to the secondary effects PMTs might cause on the PVT scintillators [11]. Then using a combination of surface current (F1) and pulse height (F8) tallies, the geometric and photon interaction efficiency of the PVT scintillator array, shown in Figure 6, was calculated.

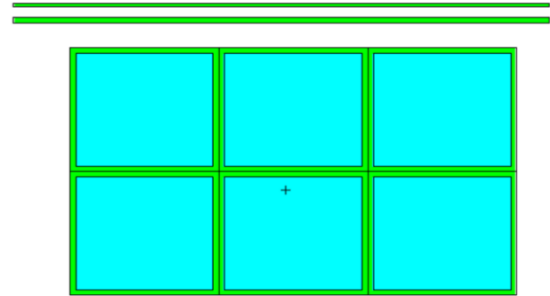


Fig 6. PVT scintillator array coupled to Photomultiplier tubes cross section

The geometric efficiency can simply be calculated as the number of particles interacting with the detection array divided by the number of particles emitted by the source as shown in Equation 1.

$$\epsilon_{\text{geometric}} = \frac{N_{\text{incident}}}{S_0} \quad (1)$$

In MCNP this is the F1 tally, as its output is already normalized to the number of particles simulated. To calculate the photon interaction efficiency, or the proportion of particles that deposit energy in a range of interest, the number

of particles eliciting a specific response (F8 tally) is divided by the number of particles incident on the detection array (F1 tally) as shown in Equation 2.

$$\epsilon_{interaction} = \frac{N_{particles\ of\ interest}}{N_{incident}} \quad (2)$$

These numbers were calculated for all three widths for both animals with Cs-137 sources placed in the front, center, and back of the animal's spine; these efficiencies were then averaged for each detector width for both animals at all three source locations. This was done in hopes of reducing the error due to the variability in radionuclide deposition within the animal. Furthermore, 5 trillion particles were simulated for each run to reduce error below one percent. The detection efficiency, the product of the geometric and photon interaction efficiency, was then plotted as a function of detection system wall width to try and extrapolate a function for wall width and detection efficiency.

RESULTS AND ANALYSIS

Geometric and Photon Interaction Efficiency

MCNP modeling yielded 6 measurements of estimated geometric and photon interaction efficiency for each detection system wall width: one front, center, and back for each animal classification. Each animal classification's efficiency measurements were plotted to visualize the effects of the radionuclide's location in the animal and the effect the detection system wall width had on efficiency. These plots are shown in Figures 7 through 10.

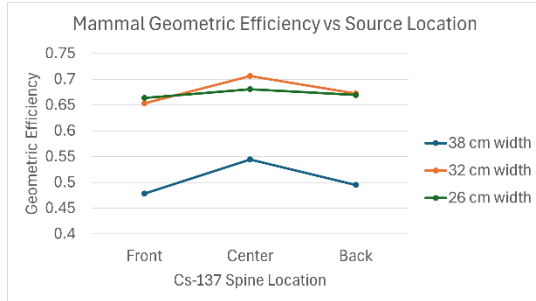


Fig 7. Geometric efficiency for mammal phantom as a function of Cs-137 source location along spine with uncertainty

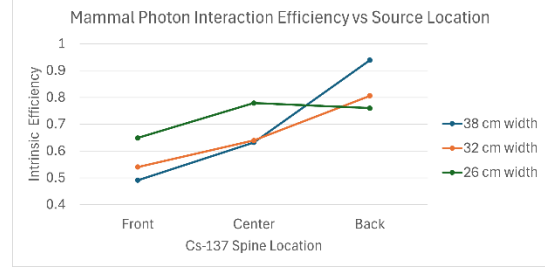


Fig 8. Photon interaction efficiency for mammal phantom as a function of Cs-137 source location along spine with uncertainty

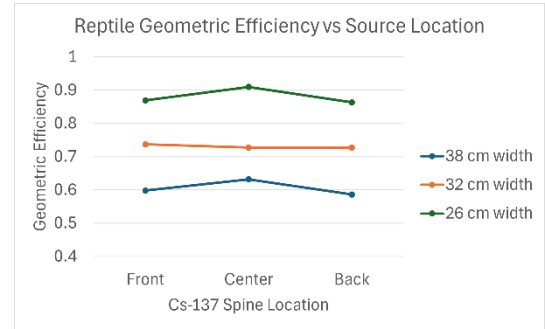


Fig 9. Geometric efficiency for reptile phantom as a function of Cs-137 source location along spine with uncertainty

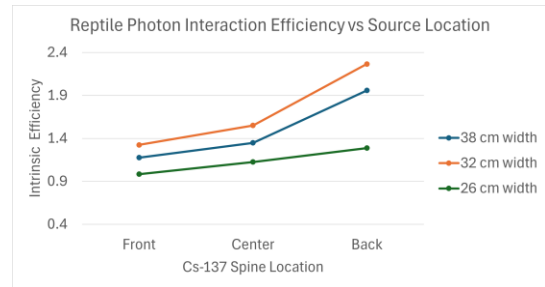


Fig 10. Photon interaction efficiency for reptile phantom as a function of Cs-137 source location along spine with uncertainty

The most notable piece of information to be gleaned from this work is that the photon interaction efficiency of the detection system with a reptile phantom is above 1 as shown in Figure 10. This likely indicates some creation of secondary particles within the animal as this efficiency is not concerned with a single photon energy. It could also be confounded by insufficient shielding between PVT scintillators in the detector arrays causing multiple interactions within the detector for a single photon. Additionally, the geometric efficiency of both animal types appears to peak when the Cs-137 source is placed at the center of the animal. This is rational as the source used is an isotropic point source; therefore, placing the source in the center of the animal will allow it to radiate more uniformly across the length of the PVT array. Sources placed at the extremities of the animal

will have a large proportion of the simulated particles escaping the detection system via the front and back respectively, decreasing the geometric efficiency. Lastly, the photon interaction efficiency for both animals appear to increase dramatically for sources located at the rear of the animal; possibly due to backscattering or secondary photon production in the simulation due to the backdoor of the detector or hindquarters of the animal; however, it should be noted this is not observed for the front wall.

Efficiency vs Width

Each detection system wall width had all 6 geometric and photon interaction efficiency measurements averaged; then the detection efficiency was found by taking the product of these two values. The new averaged detection efficiencies were then plotted against the width of the detection system shown below in Figure 11.

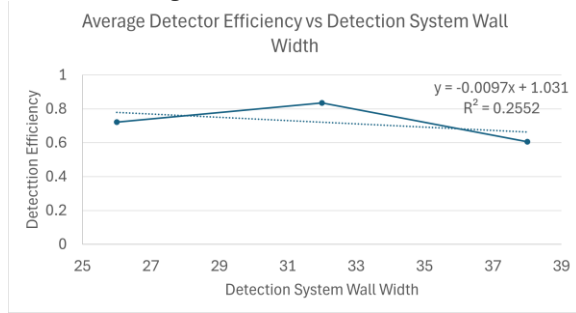


Fig 11. Detection efficiency as a function of detection system wall width with an equation of $-0.0097x + 1.031$ with uncertainty

The detection efficiency appears to peak at a wall width of 32 cm with a general decrease in efficiency from 26 to 38 cm. This is likely due to the height of the animal decreasing with size, decreasing the number of particles that interact with the top PVT scintillators of the detection array. Since the 32 cm phantom is tall enough to still have a large quantity of particles measured by the top three scintillators but smaller in diameter, attenuating fewer particles, it has a higher detection efficiency. If more data was available, it could be concluded that a quadratic fit may suit the simulation better.

Using this efficiency function, the time it would take to perform a measurement can be calculated using Equation 3 below.

$$t = \frac{\text{Counts}}{A \cdot SA \cdot \epsilon} \quad (3)$$

In this equation, counts is the number of counts you desire from the detector; this is typically 1,000 to 10,000 counts to reduce uncertainty to 3-1%. The other variables are activity limit (A), surface area of the animal (SA), efficiency (ϵ) and time of the measurement (t). Using the efficiency determined from MCNP modeling a roughly 9 second measurement would be sufficient to record 1000 counts for the smallest

animal of concern and a 1 minute 30 second measurement would be sufficient to record 10,000 counts. This is shorter than the 2 minute measurement time ORNL currently uses for a 1000 count measurement [1].

CONCLUSIONS

The CAD design and MCNP modeling laid out in this work illustrate a robust mechanical design to comfortably restrain small animals for radiation design that doubles as an effective tool for measuring small animal activity. Furthermore, the uncertainties of all simulations presented are below 0.1%, hence the apparent lack of error bars on figures, due to the magnitude of particles simulated. Additionally, supplementary tools such as the application and technician guide will enable technicians to better understand the wildlife being measured and begin tracking data in a concise manner for further longitudinal studies. Still, the detection efficiency vs wall width function has a relatively low coefficient of determination due to the small number of widths modeled. So, before implementation of this function, additional work should be completed to refine it.

FUTURE WORK

Features that could improve the functionality and usefulness of the ABA Log app have been considered. One feature that was proposed but is not yet implemented is the inclusion of a pdf version of the technician's guide accessible from the app. Including the guidebook digitally would allow for easier access in the field or anywhere else. This has not been implemented because of the additional memory requirements associated with including a pdf in the app download files. A potential solution to this is to upload the pdf file to a web server and use a web pdf viewer to access the digital file. On the other hand, this solution comes with the problem of internet access. Many of the controlled areas on the ORR may not have internet access, preventing the pdf from being accessible.

Another potential feature considered is a cloud service for backing up and syncing saved files. This is useful both for file storage redundancy and synchronization between devices, assuming multiple devices are used for data logging. The cloud backup ensures that data stored locally on a device will not be lost if the device is damaged or lost. Data synchronization capability ensures that every device has access to the same data. Additionally, data synced to a web server can be accessed on a computer for additional processing. A final concern with the app is the use of GPS on secure Department of Energy (DOE) sites. A potential solution is the ability to disable or exclude the location services for sites where security concerns exceed the usefulness of GPS location tracking.

To further validate the detection systems capabilities and ensure accurate efficiency measurements the shielding around the PVT scintillators should be increased to lower the

potential for multiple interactions from a single photon. Additionally, increasing the number of detection system and phantom width combinations will help further validate the function for determining efficiency as a function of wall width.

ACKNOWLEDGEMENT

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