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A Mercury Model of Atmospheric Transport

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A Mercury Model of Atmospheric Transport

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Abstract

Using the particle transport code Mercury, accurate models were built of the two sources used in Operation BREN, a series of radiation experiments performed by the United States during the 1960s. In the future, these models will be used to validate Mercury's ability to simulate atmospheric transport.

1 Introduction

1.1 Project Description

The goal of the project was to identify, research, and, using Mercury, recreate several radiation experiments performed by the United States during the 1960s. After modeling the sources used in the experiment, simulated spectral data was to be compared against an experimental energy spectrum for confirmation of its accuracy.

Assuming the spectrums matched, a source file containing an energy and directional spectrum would be created and used as the source in a prebuilt deck which simulates a large, multilayered atmosphere. Using this deck, data would be generated at different distances from the source and compared against what was taken during the experiment.

The intention was to use the results of these simulations to to demonstrate the validity of using the Mercury Monte Carlo code for modeling transport of neutral particles over long distances in an atmosphere.

1.2 Mercury

Mercury is a Monte Carlo particle transport code designed by LLNL. It simulates the movement of particles through mediums, using statistics and random number generators to solve the linear Boltzmann transport equation:

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$$\frac{1}{v(E)}\frac{\partial}{\partial t}\psi\left(\vec{r},\hat{\Omega},E,t\right)+\hat{\Omega}\cdot\vec{\nabla}\psi\left(\vec{r},\hat{\Omega},E,t\right)+\Sigma_t\left(\vec{r},E,t\right)\psi\left(\vec{r},\hat{\Omega},E,t\right)=Q\left(\vec{r},\hat{\Omega},E,t\right)$$
$$+\int_0^\infty dE'\int_{4\pi}d\hat{\Omega}'\Sigma_s\left(\vec{r},\hat{\Omega}'\cdot\hat{\Omega},E'\to E,t\right)\psi\left(\vec{r},\hat{\Omega}',E',t\right)$$
$$+\frac{1}{4\pi}\int_0^\infty dE'\chi\left(\vec{r},E'\to E,t\right)\nu\Sigma_f\left(\vec{r},E',t\right)\int_{4\pi}d\hat{\Omega}'\psi\left(\vec{r},\hat{\Omega}',E',t\right)$$

Mercury is capable transporting both neutral and lightly charged particles, such as neutrons, photons, and electrons.

1.3 Operation BREN

The experiment chosen to model was known as Operation BREN, short for Bare Reactor Experiment Nevada. Used in the experiment were Oak Ridge Nation Lab's Health Physics Research Reactor and a 1200 Ci ^{60}Co source. During the experiment, these sources were placed atop a 1500 foot tall tower constructed at the Nevada Test Site. Radiation detectors were placed around the tower at different distances in order to generate spectral and dosage data as a function of distance. This experiment was one of a series performed at the Nevada Test Site attempting to identify the sort of dosages people received from the bombs dropped on Hiroshima and Nagasaki.

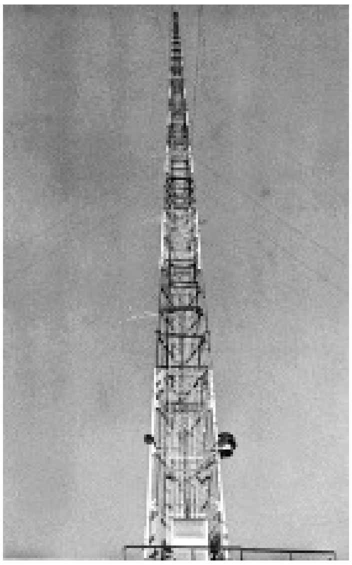

Figure 1: The BREN tower was built in the Nevada Test Site. Upon completion, approximately 1500 ft tall.[1]

2 Building the Sources

2.1 The Health Physics Research Reactor

Built by Oak Ridge National Labs, the Health Physics Research Reactor (HPRR) was essentially an uncladded, unmoderated uranium-molybdenum assembly (uranium—10 wt % molybdenum alloy).[3] It consisted of a stack of disks made of highly enriched uranium (HEU). Three control rods, all made of HEU, inserted in the top of the reactor. Additionally, a central block of HEU that attached to a steel rod ran through the center of the reactor.

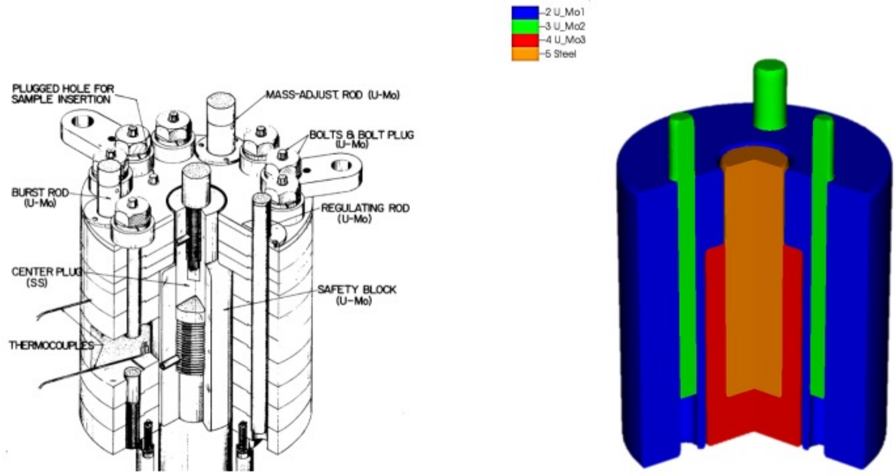

Figure 2: ORNL's Health Physics Research Reactor. On the left, a schematic diagram of the HPRR.[3] On the right, the simulated model.

In the simulated model, the HEU disks were simplified into one solid cell matching the mass and dimensions described in the technical documents.

Unable to find any experimental energy spectra taken directly at the source, no comparison was made against the simulated spectrum seen in figure 3. In order to confirm its accuracy, the simulated reactivity of the control rods and safety block was calculated using the equation:

$$R = \frac{k_1 - k_2}{k_1 k_2 \beta}$$

where k is the ratio of the current neutron population over that of the previous generation and beta is the average delayed neutron fraction of ^{235}U (.0065), and compared against those recorded during the experiment.

Figure 4 shows that the simulated and experimental reactivities match. In place any experimental energy spectrums, this was deemed enough to validate the HPRR source.

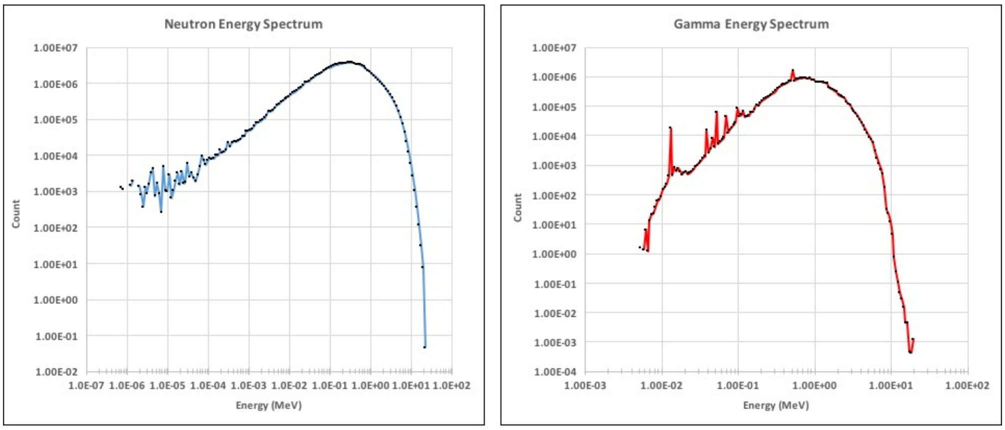

Figure 3: The simulated neutron and gamma energy spectrums taken one meter away from the center of the reactor.

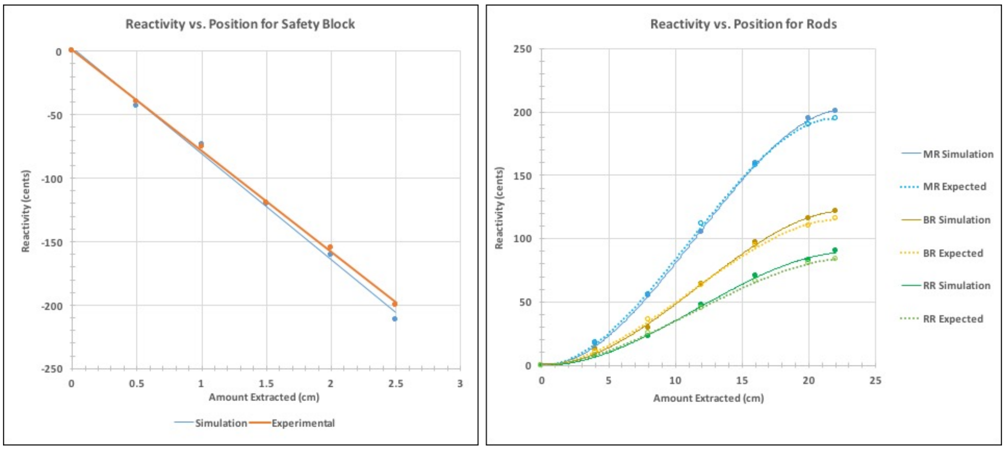

Figure 4: The reactivity of the control rods and safety block was compared against the experimental data.

2.2 1200 Ci ^{60}Co source

The cobalt source used in Operation BREN consisted of 1200 curies worth of cobalt-60 pellets arranged in a cylindrical container inside of a heavy, removable shield. These can be seen in figure 5.

In the simulation, the ^{60}Co source was simplified into a line source that emits particles with energies equal to those emitted in the radioactive decay of ^{60}Co: 1.17 and 1.33 MeV. A total particle weight of 4.44×10^{14} (the number of particles given off by a 1200 Ci source in one second) was sourced into the initial simulation used to generate the source file.

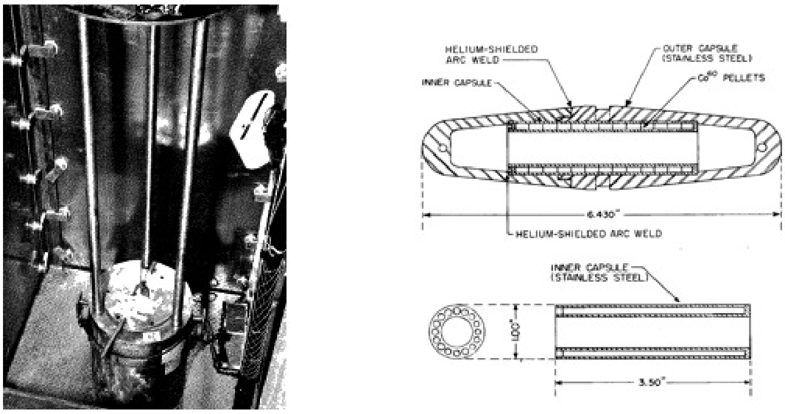

Figure 5: On the left, the ^{60}Co source inside of its shielded container.[2] On the right, a schematic of the ^{60}Co source.[1]

As can be seen in figure 6, the spectrum of the simulated Co60 source matches the expected energy spectrum of Co60.

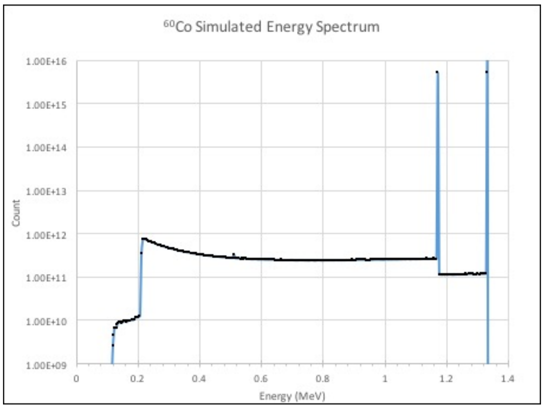

Figure 6: The simulated energy spectrum of the ^{60}Co source. Peaks occur at 1.17 and 1.33 MeV.

3 The Atmospheric Transport Deck

The atmospheric transport deck models simulates a multilayered atmosphere. Designed for long distance transport problems, it has numerous variance reduction methods implemented in it to reduce statistical noise. It further minimizes noise by using a multi-phase system to solve the transport problem.

3.1 Phase Zero

In phase zero, the source to be used in the atmospheric deck is built. After confirmation of the models accuracy, a sphere is constructed around it. A tally is implemented, recording the energy and directional spectrum of all the particles exiting the sphere. Using the results collected from this tally, a source is constructed along the surface of the sphere.

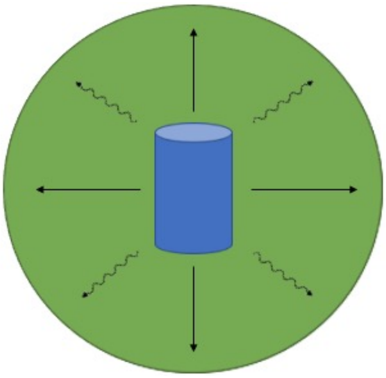

Figure 7: During phase zero, a sphere is placed around the source and used to build the source for phase one.

3.2 Phase One

In phase one, the spherical source created in phase zero is inserted into the atmospheric transport deck. When run, the deck constructs two concentric spheres around the location data is desired. In a process similar to phase zero, the particles which strike the outer and inner sphere are tallied and the ratio between the two is used to generate a new source which lies along the inner sphere.

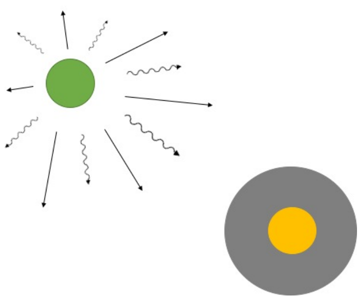

Figure 8: During phase one, particles travel through the simulated atmosphere and are tallied along the surface of two concentric spheres.

3.3 Phase Two

During phase two, the new source is used to run a much smaller transport calculation then before. Since the distances being modeled are on the order of meters and not kilometers, many times the number of particles can be used, further reducing noise. It is during this phase that desired data is obtained.

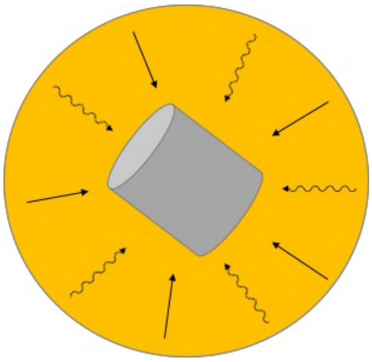

Figure 9: During phase two, particles are sourced into a small sphere and data is collected.

4 Preliminary Results

In figure 10, a preliminary neutron spectrum at 750 yd is compared against an experimental spectrum taken at the same distance. The simulated neutron spectrum was generated without using the atmospheric transport deck. It was made by constructing a sphere with a radius of 750 yd around the HPRR source and tallying the energy spectrum of the particles exiting its surface. The data was then shifted so that its peak aligned with the height of the experimental plot.

Statistical noise can be seen interfering with the data in both plots at low energies. Although the two have very similar shapes after roughly .01 eV, it cannot be determined whether or not they are the same because the correlation between channel number and energy is not known. Although assumed to scale linearly, this information was not included in the technical reports.

5 Conclusion

Although the preliminary results are promising, there is still much that needs doing before Mercury's capabilities can truly be validated. Of the little data

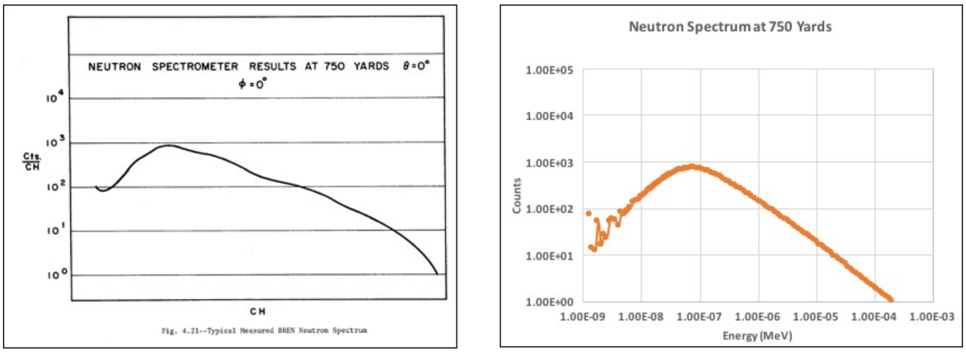

Figure 10: On the left, the experimental neutron spectrum measured at 750 yd.[4] On the right, the simulated neutron spectrum at 750 yards.

contained in BREN's documentation, the most promising are a series of tables and plots containing data on dosage as a function of distance. There are drawbacks to this, however, as generating accurate data on dosages can be more complicated then spectral data. Specifically, comparing dosages introduces new elements that can and likely will add to the experimental uncertainty. In order to generate accurate dosage data, the correct material composition and geometric parameters must be known. As the technical documents do not contain detailed accounts of this information, approximations and assumptions will have to be made, increasing the likelihood of error.

As only phase zero was able to be completed, phases one and two need to be run and simulated dosage data be generated at different distances from the source.

Research into another radiation experiment known as Operation HENRE was conducted alongside BREN. Similar to BREN, HENRE also used the BREN tower, utilizing a d-t fusion source to produce 14.1 MeV neutrons. Although only a basic model of HENRE was able to be built, HENRE could serve as a viable alternative to BREN for validating Mercury's atmospheric transport capabilities.

6 Citations

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3. Lundin, M. I. *Health Physics Research Reactor Hazards Summary.* Aug. 24, 1962.

4. Thorngate, J. H. *CEX-62.12 Energy and Angular Distribution of Neutrons and Gamma Rays.* Feb., 1967.