Radiation Mapping of a Subcritical Graphite Assembly

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INTRODUCTION

This summary presents the results of an initial radiation mapping of the Purdue University subcritical assembly. This study aims to conduct a comprehensive radiation mapping of the Purdue University subcritical assembly in order to understand the distribution of ionizing radiation in the facility and evaluate the safety and protection of personnel and the general public. State-of-the-art radiation detection equipment was used and a systematic grid pattern to collect data on radiation levels throughout the room. The data was analyzed to identify potential hot spots and determine the overall radiation level of the room. The results of the study revealed slightly elevated levels of radiation near the subcritical assembly, as expected, and slightly higher above background radiation levels in certain areas of the room. The study also provided valuable information on the effectiveness of existing radiation protection measures and identified areas where additional measures may be needed. These areas include those around the subcritical assembly and near the sources that are inside the room. The findings of this study provide valuable information for the safe operation and management of subcritical assembly facilities.

Background

A subcritical assembly is a type of nuclear reactor that operates below the critical point, which is the point at which a sustained nuclear chain reaction can occur. In a subcritical assembly, the number of neutrons produced by fission is not sufficient to maintain the chain reaction, and the reactor relies on an external source of neutrons, typically a particle accelerator or a neutron source, like AmBe, to sustain the reaction. Subcritical assemblies are designed for research and development, production of medical isotopes, and the destruction of nuclear waste. They can also be used as a means of producing energy, however, they are not as efficient as critical reactors. The Purdue subcritical assembly has dimensions of 68”x100” and is made out aluminum clad natural metallic uranium slugs with high purity graphite as a moderator. It is used for experimental lab courses and teaching purposes.

Radiation mapping is the process of measuring and mapping the distribution of ionizing radiation in a given area. This can be done with various types of radiation detection instruments, including Geiger counters, scintillation detectors, and thermoluminescent dosimeters. The data collected during a radiation mapping survey is used to create a map or image of the radiation levels in the area, which can be used to identify areas of high radiation, track the movement of radioactive materials, and evaluate the effectiveness of radiation protection measures.

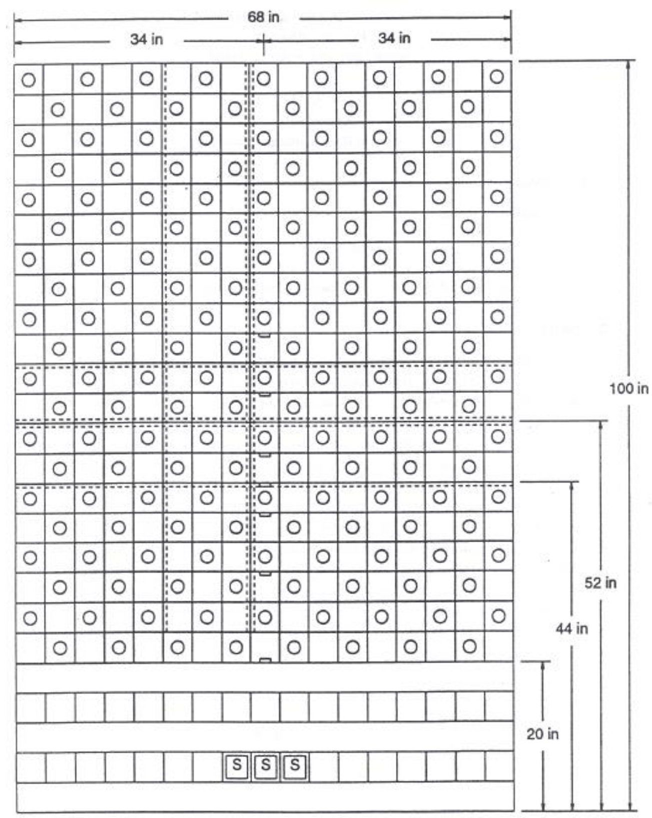

Fig. 1. Purdue University subcritical pile layout

The use of subcritical assemblies in nuclear industry has increased the need for radiation mapping in order to check for contamination and to plan decontamination and decommissioning. The radiation mapping of a subcritical assembly is critical for the safe operation and management of these facilities, as it provides valuable information on the distribution of ionizing radiation in the facility and the effectiveness of existing radiation protection measures.

10 CFR 20 is a regulation issued by the U.S. Nuclear Regulatory Commission (NRC) that establishes the

standards for protection against ionizing radiation. It outlines the limits for radiation exposure to both occupational and the general public and provides guidelines for monitoring and controlling exposure to ionizing radiation. The regulation applies to all activities that involve ionizing radiation, including the use of radioactive materials, the operation of nuclear reactors, and the disposal of radioactive waste.

10 CFR 20 provides specific guidance on the use of radiation monitoring instruments, the calculation of dose, and the reporting of radiation exposure. It also establishes guidelines for emergency response and preparedness in the event of a release of radioactive material. The regulation is updated periodically to incorporate new information and advancements in radiation protection.

According to 10 CFR 20, the limits for radiation exposure to workers and the public are established to protect them from harmful effects of ionizing radiation. For workers, the annual dose limit is set at 50 millisieverts (mSv) per year, (5000 mrem) averaged over five years, with a single-year dose limit of not more than 100 mSv (10000mrem). For the general public, the annual dose limit is set at 1 mSv (100 mrem) per year, in addition to natural background.

These limits are based on extensive scientific studies and take into account the risks associated with radiation exposure. They are designed to be protective of public health and safety while also allowing for the beneficial uses of ionizing radiation in medicine, industry, and research.

Methods

Radiation levels in the subcritical assembly were measured using a Geiger counter (Mazur Instruments PRM-9000). The meter was calibrated prior to use and was verified to be in good working order according to the manufacturer's specifications. The neutron measurements were carried out with a He-3 detector with an operating voltage of 960V. An ion chamber (Ludlum) was also used to obtain dose rates at three representative points, centered off of the subcritical pile, for later use in correlating observed counts with a dose rate.

The data collection process involved dividing the subcritical assembly room into a grid and then taking measurements at each grid coordinate. The spacing of the 2D grid was 50cm. At each point, we placed or held the radiation detector and the neutron detector 100cm from ground level and measured the radiation levels for one minute. To get a z-profile of the radiation field, these measurements were taken at 6 different heights, starting from ground level in increments of 50cm all the way to just above the subcritical pile at three representative distances from the subcritical pile, 0 cm, 250cm, and 500cm away. The ion chamber measurements were taken at 3 points, starting from centerline, then 250cm from centerline and finally 500cm from the assembly's centerline. To ensure the accuracy and consistency of the data, we performed regular checks on the data collected. The neutron and gamma measurements were done in tandem to increase efficiency. It was also ensured that the instruments were placed or held at the same angle for every measurement to standardize the process.

The data collected was entered into a spreadsheet program (Microsoft Excel) and analyzed using descriptive statistics. The data was read by a script made in MATLAB to visualize the distribution of the radiation levels in the room. The coordinates where it was not possible to get a measurement were registered as 0s.

TABLE I. Descriptive Statistics of the Gamma and Neutron Measurements

	Gamma (cps)	Neutron (cps)
Minimum	2.27	3.53
Maximum	64.20	42.70
Range	61.93	39.17
Mean	13.70	18.19
Median	10.20	17.32
Mode	4.97	17.05
Variance	113.89	60.33
Standard Deviation	10.67	7.77

Data

The results of our preliminary radiation mapping of the subcritical assembly showed that the average radiation levels in the room were slightly higher than the background levels in the surrounding area. The average radiation level measured by the GM detector was 13.70cps, with a standard deviation of 10.67cps, while the average neutron count measurement was 18.19cps, with a standard deviation of 7.77cps. The distribution of the radiation levels in the room is shown in Figure 1, which shows a plot of the gamma radiation levels measured by the PRM-9000 Geiger counter, while the neutron distribution is shown in Figure 2. From previous measurements in the Purdue University Nuclear Engineering Radiation Laboratories, a correlation between neutron count rate and dose rate was determined for the He-3 detector. This conversion factor was established to be 0.026911 mrem/h/counts/s which comes out to 2229.5 CPM/mrem/hr. The factor established from our measurements with the ion chamber and radiation meter comes out to be 2831.23 CPM/mrem/hr. This is in contrast to the PRM-9000 conversion factor of 3500 CPM/mrem/hr, but that is most likely due to it being calibrated with a Cs-137 source and that the gammas it was measuring were lower in energy than 662 keV. These factors were multiplied with the data in cps accordingly to get the dose rate in the room then mapped as shown below. The total dose rate is found by summing the neutron dose rate and the gamma dose rate.

TABLE 2. Descriptive Statistics of the Gamma and Neutron Dose Rates

	Gamma (mrem/hr)	Neutron (mrem/hr)
Minimum	0.048035641	0.095086
Maximum	1.360538895	1.149111
Range	1.312503254	1.054024
Mean	0.290398182	0.489782
Median	0.216160385	0.466013
Mode	0.105254567	0.458837
Variance	0.051147274	0.043689
Standard Deviation	0.226157631	0.209019

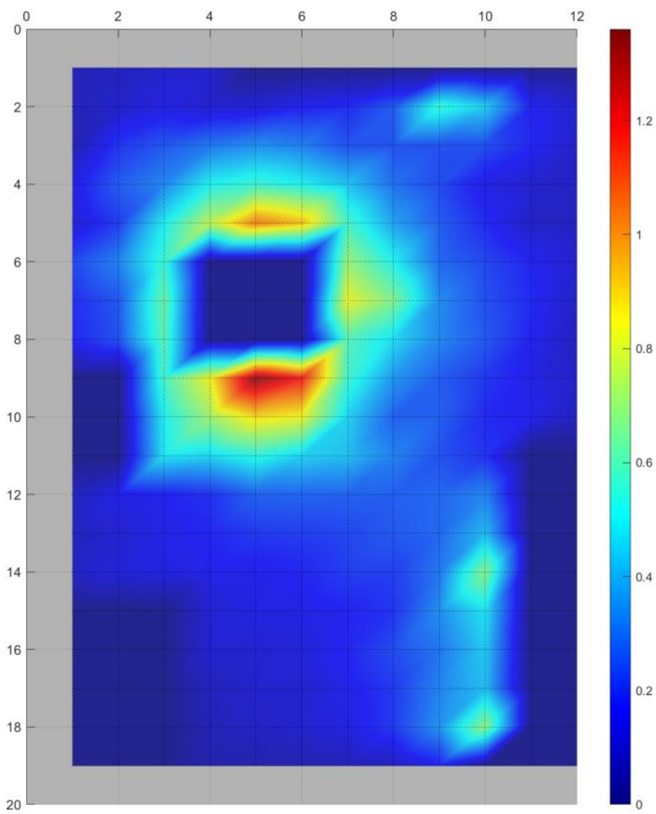

Fig. 2. Top view of the gamma dose of the subcritical assembly room.

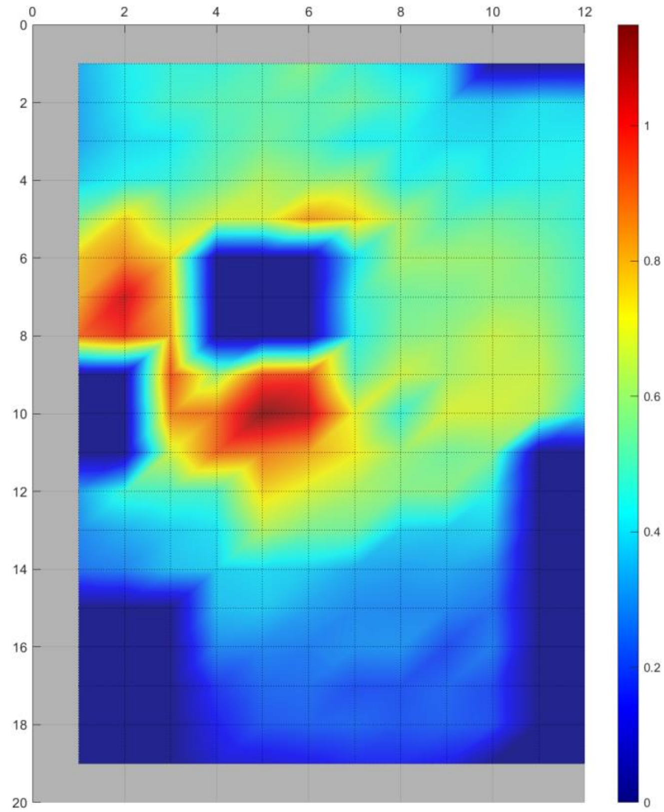

Fig. 3. Top view of the neutron dose of the subcritical assembly room.

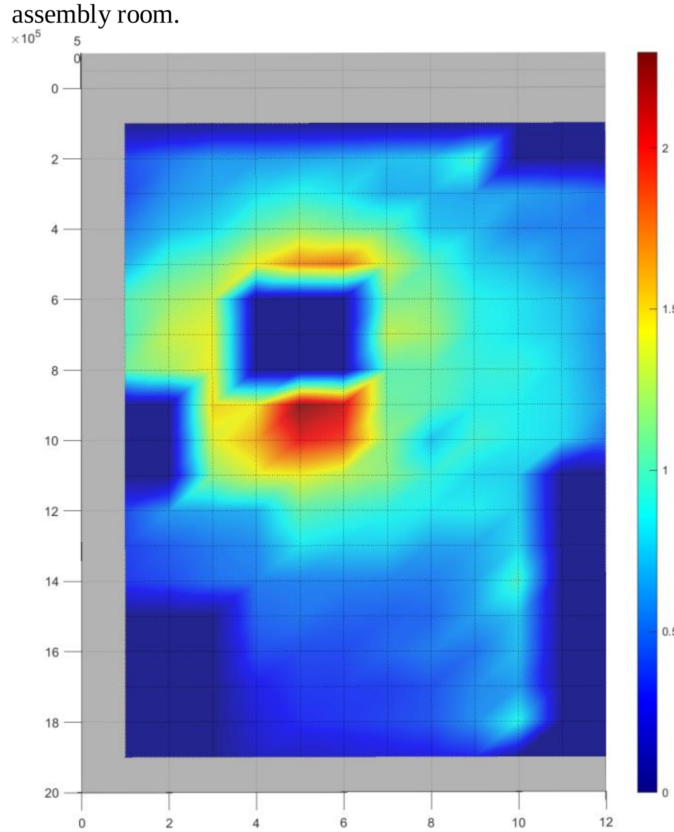

Fig. 4. Top view of the total dose of the subcritical assembly room

Results

As can be seen from the maps, the radiation levels within the room were consistent, with little variation across the different locations. The highest levels of radiation were found near the subcritical assembly, for both neutrons and gammas, with decreasing levels as the distance from the assembly increased. On average, the radiation levels near the assembly were approximately 0.78 mrem/hr, while the levels at the edges of the room were approximately 0.5 mrem/hr. The elevated levels at coordinates (9,2) and along the lines of (10,14) to (10,20) are attributed to natural uranium slugs present in cabinets inside the room.

The count rate measurements were converted to dose rate using a conversion factor of CPM/mR/hr. The dose rate at the highest point near the assembly was found to be approximately 2.3 mR/hr, while the lowest dose rate was approximately 0.15 mR/hr. These values are within the accepted safe limits for radiation exposure and pose no immediate risk to personnel in the area. Figure 3 is essentially a concatenation of Figures 1 and 2.

Conclusion

Our study on the radiation mapping of the Purdue University subcritical assembly showed that the radiation levels in the room were slightly higher around the subcritical pile than the background levels in the surrounding area. The results showed that the radiation levels were consistent and well-distributed, with low standard deviations and a clear distribution shown in the maps.

The study provides important information on the radiation levels in a room containing a subcritical assembly, which can be used to inform safety measures and risk assessments for workers and visitors in the area. The results can also be used as a baseline for future studies and comparisons on the radiation levels in similar rooms and facilities.

In conclusion, the results of our study contribute to the understanding of the radiation levels in a room containing a subcritical assembly and can be used to inform safety measures and risk assessments for workers and visitors in the area. The results can also be used as a baseline for future studies and comparisons on the radiation levels in similar rooms and facilities. In the future we can conduct a more accurate experiment with multiple readings for even longer time intervals to reinforce the reliability of our findings.

REFERENCES

1. S. GLASSTONE, A. SESONSKE, *Nuclear Reactor Engineering,* (1967)
2. J. LAMARSH, A. BARATTA, *Introduction to Nuclear Engineering, (*1982)
3. G. KNOLL, *Radiation Detection and Measurement,* (1979)
4. F. ATTIX, *Introduction to Radiological Physics and Radiation Dosimetry, (1991)*
5. G. SHANI, *Handbook of Radiation Dosimetry: Instrumentation and Methods,* (2000)
6. Y. MIYAWAKI, An Experimental Study on Subcritical Assembly with Neutron Source, Journal of Nuclear Science and Technology (1968)
7. 10 CFR 20
8. MAZUR INSTRUMENTS NUCLEAR RADIATION MONITOR USERS GUIDE (2017)