

Assessment of Dose Reduction in Residential Buildings around the Research Reactor in an Emergency

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1. Introduction

30 MW Gerrit Agustinus Siwabessy Multi-Purpose Reactor (RSG-GAS) is the largest research reactor in Indonesia. The reactor is a pool-type reactor, used mainly for neutronic, thermohydraulic, reactor system safety, production of radioisotopes, and Neutron Activation Analysis (NAA). It is located in Setu village, Muncul sub-district, South Tangerang district, Banten Province [1]. The reactor is currently operated by the National Research and Innovation Agency of Indonesia (BRIN). The RSG-GAS is located in the B.J. Habibie Science and Technology Area. Previous study [1] conducted a simulated Beyond Design Basis Accident (BDBA) at RSG-GAS using ORIGEN 2.1, a Monte Carlo Code. The accident was based on Anticipated Transient Without Scram (ATWS), which was caused by the blockage of the coolant flow in the reactor fuel. This accident resulted in the melting of 5 fuel bundles. Following the Fukushima accident, BDBA became a critical focus

for emergency preparedness and response at the nuclear reactor. Table 1 below shows the source term resulting from the simulated accident by ORIGEN 2.1. The simulation, conducted by ORIGEN 2.1, lasted for 1 hour following the accident.

The RSG-GAS location is surrounded by residential houses, with the nearest house located 500 meters from the reactor itself. Radiation safety has the purpose of protecting workers, people, and the environment from the risk of ionizing radiation [2]. Therefore, to protect the residents living near the reactor, an analysis of the effective dose caused by the accident is needed for emergency preparedness and response. This study aims to analyze the effective dose rate in residential houses, with 1-story house and 2-story house as a comparison, using the Particle and Heavy Ion Transport code System (PHITS), a Monte Carlo code. This study will serve as a preliminary step in preparing the comprehensive emergency preparedness and response program for the RSG-GAS.

Table 1. Source Term of ORIGEN2.1 Simulated Accident [1]

Radionuclide Group	Nuclide	Source Term (Bq)	Radionuclide Group	Nuclide	Source Term (Bq)
Noble Gas	⁸⁵ Kr	8.38x10 ¹²	Strontium and Barium	⁸⁹ Sr	1.67x10 ¹⁰
	^{85m} Kr	6.31x10 ¹⁴		⁹⁰ Sr	3.33x10 ⁰⁸
	⁸⁷ Kr	8.64x10 ¹⁴	Nobel Metal	¹³⁹ Ba	1.87x10 ¹⁰
	⁸⁸ Kr	1.63x10 ¹⁵		¹⁴⁰ Ba	1.81x10 ¹⁰
	¹³³ Xe	3.89x10 ¹⁵		¹⁰⁵ Ru	3.22x10 ⁰⁹
	¹³⁵ Xe	6.27x10 ¹⁴		¹⁰⁶ Ru	5.82x10 ⁰⁸
Halogen	¹³¹ I	4.11x10 ¹¹		^{103m} Rh	1.00x10 ¹⁰
	¹³² I	6.20x10 ¹¹		¹⁰⁵ Rh	2.68x10 ⁰⁹
	¹³³ I	9.79x10 ¹¹	Lanthanides	¹⁴⁰ La	1.84x10 ¹⁰
	¹³⁴ I	1.10x10 ¹²		⁹⁰ Y	3.57x10 ⁰⁸
	¹³⁵ I	9.15x10 ¹¹		⁹¹ Y	2.02x10 ¹⁰
Alkali Metal	¹³⁴ Cs	9.08x10 ⁰⁷		⁹⁵ Nb	2.15x10 ¹⁰
	¹³⁷ Cs	3.45x10 ⁰⁸		¹⁴³ Pr	1.69x10 ¹⁰
	⁸⁸ Rb	1.05x10 ¹⁰		¹⁴⁷ Nd	6.56x10 ⁰⁹
Tellurium	¹³² Te	1.23x10 ¹⁰	Cerium	¹⁴¹ Ce	2.01x10 ¹⁰
	¹³⁵ Sb	4.00x10 ⁰⁸		¹⁴³ Ce	1.71x10 ¹⁰
	¹²⁷ Sb	4.00x10 ⁰⁸		¹⁴⁴ Ce	9.06x10 ⁰⁹

2. Method and Material

PHITS is a Monte Carlo code that was developed by the Japan Atomic Energy Agency. The PHITS code is a general-purpose Monte Carlo code that can simulate the behavior of most particles up to an energy of 1 TeV [3]. This model is capable of handling complex geometry and material composition, making it suitable for various applications, including space radiation protection, accelerator design, radiation shielding, and medical physics [4]. In this study, the geometry of residential houses was simulated using the most common house design in Indonesia. For this study, two types of houses for comparison were selected, which are 1-story houses and 2-story houses. Table 2 below describes the design of the houses.

Table 2. House Description

	1-story House	2-story house
Length	6 meters	6 meters
Width	6 meters	6 meters
Height	4.5 meters	6.15 meters
Bedroom	2	3
Bathroom	1	2
Living Space	1	3

For the house wall composition, the most common type of Indonesian house wall is made of Portland concrete. The house design will also feature wooden doors and glass windows. The roof of the house will be made of clay, which is the most common house roof composition [5]. Table 3 below shows the material composition of each material. For calculating the effective dose, the PHITS simulation will utilize the source terms listed in Table 1. A simulation will be conducted to calculate the effective dose after 1 hour of the events. The PHITS simulation will consist of 10,000 particles across 10 batches.

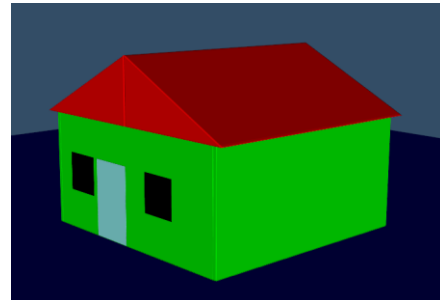
Table 3. Material Composition [6]

Material	Density (g/cm ³)	Composition (Elemental atom fraction)
Air	0.001205	C (0.000124) N (0.755267) O (0.231781) Ar (0.012827)
Concrete Portland	2.3	H (0.168753) C (0.001416) O (0.562526) Na (0.011838) Mg (0.001400) Al (0.021354)

		Si (0.204119) K (0.005656) Ca (0.018674) Fe (0.004264) Ar (0.004671)
Wood	0.64	H (0.462413) C (0.323396) N (0.002773) O (0.208782) Mg (0.000639) S (0.001211) K (0.000397) Ca (0.000388)
Soil	1.52	O (0.670604) Na (0.005578) Mg (0.011432) Al (0.053073) Si (0.201665) K (0.007653) Ca (0.026664) Ti (0.002009) Mn (0.000272) Fe (0.021050)
Clay	0.84	H (0.228604) C (0.749029) N (0.006169) O (0.014402) S (0.001796)
Glass	2.4	O (0.603856) Na (0.088144) Si (0.251795) Ca (0.056205)

3. Result and Discussion

At first, the PHITS simulation will conduct a geometry simulation for the building. As shown in Fig. 1 below, the geometry of the 1-story and 2-story houses was created using PHITS. Each color difference corresponds to a different material composition. After the geometry had been completed, the radiological release was simulated. Target 2-story house is located in 1st floor and 2nd floor.



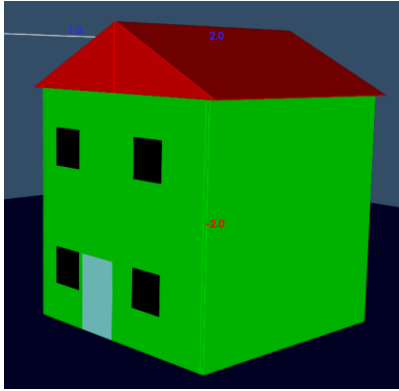


Fig. 1 Geometry of 1-story (top) and 2-story (bottom)

Table 4 below presents the results of the BDBA simulated event for residential houses. The effective dose rate simulated by PHITS shows different results: the 2-story house can decrease the incoming effective dose rate by 29.4% for 1st floor and 16.2% for 2nd floor, whereas the 1-story house can only decrease it by about 12.7%. This difference was caused by the geometry of the building itself, where the two-story house has a larger geometry compared to the one-story house. The wall of the 2-story house covers a larger area (having more volume) than the 1-story house, thereby reducing the effective dose rate more than the 1-story house. With both buildings composed of the same material, but with different areas and volumes, this has the most significant effect on reducing the incoming effective dose rate. Difference at 1st floor and 2nd floor of 2-story house is due to the 1st floor have more shielding (concrete floor at 2nd floor) than the 2nd floor, therefore it can reduce more of the incoming effective dose. From the simulation results, it is shown that most of the incoming radiation from Table 1 emits beta and gamma radiation. The composition of the material for the wall and roof shows an effective reduction in the incoming effective dose. Future studies need to conduct a materials comparison of the composing material to determine the most effective material for reducing the effective dose.

Table 4. Effective Dose Rate Simulation Result

Effective Dose Rate	1-story house	2-story house	
		1 st floor	2 nd floor
Outside House (mSv/hour)	49.04	51.92	
Inside House (mSv/hour)	3.85	1.76	3.21

4. Conclusion

Simulation results using the Monte Carlo code PHITS show that structural and building materials play a significant role in reducing the effective dose rate of external radiation in the event of a Beyond Design Basis Accident (BDBA) at the RSG-GAS facility. Two-story houses, with greater wall volume and surface area, are able to significantly reduce the incoming effective dose rate, up to 29.4% and 16.2%, whereas one-story houses achieve only 12.7%. These findings confirm that increasing the volume and thickness of protective building materials can be an effective way to mitigate radiation risk for residents living near nuclear facilities. This study provides a preliminary basis for planning emergency preparedness and response systems. It can be utilized to offer recommendations for the design of buildings or shelters in areas at risk of radiation exposure. For future work, it is highly recommended to consider variations in building materials, weather conditions, and different exposure scenarios to gain a more comprehensive understanding of community protection strategies in the event of nuclear disasters.

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References

- [1] M. S. M. S. S. K. J. P. E. H. H. S. P.M. Udiyani, "Assessment of dose consequences based on postulated BDBA (beyond design basic accident) A-30MWt RSG-GAS after 30-year operation," *Progress in Nuclear Energy*, 2021.
- [2] Republic of Indonesia Government, Peraturan Pemerintah Republik Indonesia Nomor 45 Tahun 2023 tentang Keselamatan Radiasi Pengion dan Keamanan Zat Radioaktif, Republic of Indonesia Government, 2023.
- [3] T. S. & e. al, "Recent improvement of the particle and heavy ion transport code system - PHITS version 3.33," *Nuclear Engineering and Technology*, pp. 127-135, 2024.

- [4] K. N. T. Sato, "Features of particle and heavy ion transport code system (PHITS) version 3.02," *Journal of Nuclear Science and Technology*, pp. 684-690, 2018.
- [5] E. Hausler, "Design and construction of confined masonry houses in Indonesia: challenges, performance in earthquakes, and need for future research," *Confined Masonry Network, draft for discussion*, 2008.
- [6] Pacific Northwest National Laboratory, Data Mining Analysis and Modelling Cell, Compendium of Material Composition Data for Radiation Transport Modelling, United States of America: United States Department of Energy, 2021.