# Monte Carlo Shielding Analysis for Transporting Research Reactor Reflector

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## 1. Introduction

The Triga Mark II research reactor in Indonesia underwent an upgrade in 1996. This process generated various types of radioactive wastes including solid radioactive materials and activated reactor components such as pipes, bolts and elbows. Among these wastes, one of the most challenges to manage has been the reactor reflector, which is made of graphite and contains the radioactive Cobalt-60 ($^{60}Co$) [1]. The primary objective of this study is to perform the shielding design for the transportation of the reactor reflector containing $^{60}Co$ from the research reactor to the Radioactive Waste Management Installation (RWMI). This study involves the Particle and Heavy Ion Transport Code System (PHITS) for simulating and optimizing the shielding design to ensure compliance with regulatory dose-rate limits at both the surface and 1 meter from the transport container. Specifically, the design must adhere to the dose-rate limit requirements set by Government Regulation No. 58 of 2015 [2]. Fig. 1 shows the reflector came from the reactor facility.

Fig. 1. Reflector Waste and Initial Design of Reflector's Geometry.

## 2. Method and Results

Government Regulation No. 58 of 2015 stipulates that the dose rate for transporting radioactive waste in category III-Yellow at the surface of the transport container must not exceed 2 mSv/hour, and fulfill transport index value of 1-10, which can be calculated by measuring dose rate (mSv/h) at 1 meter from the container multiple by 100 [2,4]. In this study, PHITS was used to simulate radiation transport and shielding [3].

### *2.1 Source Materials*

The source term for the shielding analysis was based on the specific characteristics of the reflector. Detailed information includes:

- Reflector Composition: The reflector is primarily composed of graphite and contains $^{60}Co$.
- Activity: $^{60}Co$ has an activity of 4.3 Ci.
- Gamma Energies: The primary gamma energies emitted by $^{60}Co$ are 1.1732 MeV and 1.3325 MeV.
- Dimensions: The reflector has a diameter of 116.2 cm and a height of 126 cm [1].

### *2.2 Simulation Setup*

The setup for the PHITS simulation included defined geometry, dimensions, and material properties of the transport container. The materials used were concrete, lead, iron and air. PHITS code parameters used the physical properties and density of each composition. For the geometry input parameter, the following materials were used as shown in Table I.

Table I: Material Composition for Transport Container [5]

| Material | Density (g/cm$^3$) | Thickness (cm) |
|---|---|---|
| Source: Graphite (reactor grade) | 1.7 | 30.6 |
| Air (inside source) | 0.001205 | 27.5 |
| Plat Fe (inner body structure) | 7.15 | 0.5 |
| Concrete Portland (body structure) | 2.3 | 25 |
| Plat Fe (outer body structure) | 7.15 | 0.5 |
| Pb (top cover) | 11.35 | 3 |
| Concrete Portland (top cover) | 2.3 | 10 |
| Fe (top cover) | 7.15 | 2 |

The cylindrical types simulated within the layer of shielding from inside to outside were iron plat, concrete, and iron plat to support the structure. For the top cover, a cylindrical layer from lead, concrete, and iron plat was also used for the handling mechanical. Fig. 2 shows an illustrated design for the transport container.

Fig. 2. Illustrated Design for Transport Container.

### *2.3 Simulation Results*

The results of the geometry input parameter are shown in Fig. 3. The geometry shows air inside the source and a gap between the source and the transport container. Additionally, air is used outside the transport container as a medium for dose-rate transfer to the worker.

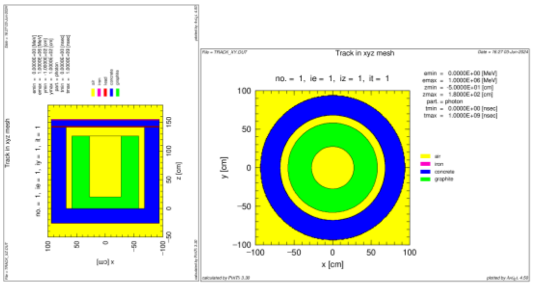
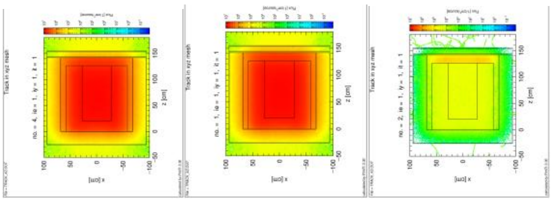


Fig. 3. Geometry in axial and radial direction for Transport Container Design.

### *2.4 Energy Distribution for photon and electron*

$^{60}$Co is a radioactive isotope that decays by beta emission, producing energetic beta particles (electrons) and gamma radiation (photons) [6]. These beta particles are significant because they contribute to the radiation dose close to the source but are typically absorbed quickly in materials and are less of a concern for shielding design compared to gamma rays. The more critical aspect of shielding is the gamma radiation. $^{60}$Co emits two primary gamma photons with energies of approximately 1.17 MeV and 1.33 MeV [7]. These high-energy photons can penetrate materials more deeply, and requiring robust shielding to protect against them. Concrete is widely used as a shielding material in radiation protection due to its advantageous properties. Its high density, around 2.3 g/cm³, allows it to effectively attenuate radiation by absorbing and scattering gamma rays, and significantly reducing their intensity. The substantial mass of concrete structures further enhances their shielding capabilities, as thick layers can create effective barriers against radiation. The energy distribution results for all (photon+electron), photons, and electrons were as shown in Fig. 4.



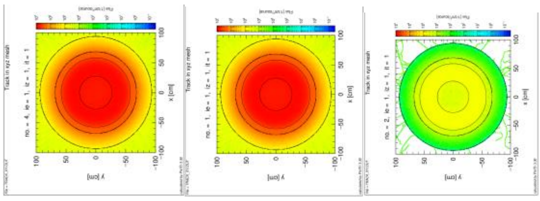


Fig. 4 Energy distribution for all, photons and electrons.

### *2.5 Dose Rate Distribution*

The dose rate distribution along the radial direction shows the effective dose that would be received by the radiation worker. The radial dose-rate distribution refers to the variation of the radiation dose rate at different distances from the center of the source, moving outward horizontally. In the context of the transport container, this distribution helps assessing the effectiveness of the shielding materials in reducing radiation levels as one moves away from the container. The simulation indicated that the dose rate along the axial direction also decreased as one moves away from the container. The use of lead and concrete layers in the top cover plays a significant role in reducing the dose rate in this direction. The axial dose-rate distribution chart showed that the dose rates above and below the container were well within acceptable limits, ensuring that the shielding design was effective in all directions. Fig. 5 shows the dose rate from the center of the transport container in distances.

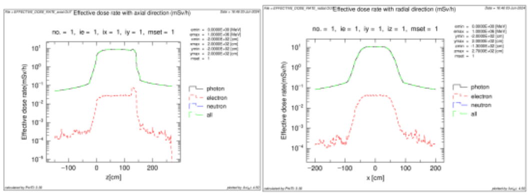


Fig. 5 Axial and radial effective dose rate distribution.

The PHITS simulation provided a detailed analysis of the dose rate distribution around the transport container. The effective dose rate chart is a crucial component in evaluating the transport criteria limits. Table II presents the dose rate in mSv/h at the surface and 1 meter, respectively.

Table II: Effective dose rate results

| Direction | Surface (mSv/h) | At 1 meter (mSv/h) |
|---|---|---|
| Body side (radial) | 0.164 | 0.085 |
| Upper side (axial) | 0.149 | 0.092 |
| Below side (axial) | 0.111 | 0.056 |

The simulation demonstrated that the combination of iron, concrete, and lead effectively reduced these high energy photons, thereby lowering the dose rate around the container. The design successfully met the category Transport Criteria III-Yellow. The dose rate at the surface of the transport container was 0.164 mSv/h not exceeding 2 mSv/h. The dose rate at 1 meter from the surface was 0.085 mSv/h below the criteria limit of 0.1 mSv/h (for max transport index value 10).

## 3. Conclusions

PHITS can offer a comprehensive analysis due to its advanced capabilities in simulating complex geometries and material compositions. The shielding design meets the transport criteria requirements for category III-Yellow outlined in Government Regulation No. 58 of 2015:

• Surface dose rate is 0.164 mSv/h, below the limit of 2 mSv/h

• Dose rate at 1 meter is 0.085 mSv/h, complying with the transport criteria limit of 0.1 mSv/h

This study demonstrates the importance of advanced simulation tools and iterative design processes in optimizing radiation shielding.

## Acknowledgment

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