Design of reflector TRIGA mark II Bandung waste container shielding using micro shield 7.02.

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Abstract. Reflector TRIGA Mark II Bandung waste container shielding using Microshield 7.02 has been conducted. In 1996, TRIGA Mark II power was upgraded from 1MWt into 2MWt, and the reflector was one part of the reactor core that was changed. Reflector waste consists of graphite with activated Co-60. In 2015 the activity was 0.557 Ci with 1,221.5 Kg weight. This large radioactive waste needs to be removed from Bandung Nuclear Area into PTLR- Serpong Nuclear Area. This removal process needs calculations and the basic design of the waste container. Pure lead material is planned to be used for attaining requirements standards of radioactive container category base on Transport Index score. In addition, MicroShield 7.02 is a software that is used for helping to analyze shield thickness and could count exposure rate out of the waste container. This software was also used in this research to calculate the lead thickness and demonstrate the radioactivity in several points. The result of simulation with this software is; lead thickness for the container is 3 cm; the container category is III-Yellow with; Transport Index score is 189 or bigger than 10. With tubular shape with 3 cm thickness it will use 1,945.13 kg pure lead. Then, the dose rate on the surface of the container is 128.6 mSv/hr.

1. Introduction

The oldest nuclear research reactor in Indonesia is in the Center of Applied Nuclear Technology in Bandung Nuclear Area. Within history it had been upgraded from the TRIGA Mark II reactor to TRIGA 2000 in 1996. This upgrading process is for increasing the reactor power, from 1 MWt into 2 MWt. Some part of the reactor core was changed and replaced with the new ones. One component that is disassembled and replaced is the reflector component. Structurally this reflector is in part closest to the reactor’s fuels. It was used during the operation of the reactor from 1971 until 1996. So, the reflector of the former TRIGA Mark II reactor became radioactive waste with exposure rate 14 R/hour. Some related researches on the TRIGA Mark II reflector waste in Bandung has been conducted by several researchers.

Daryoko (2002) researched the management of reflector waste (graphite) as a result of dismantling the TRIGA Mark II reactor using electrolysis. The method used was to adopt previous studies by
searching for literature. In this research, graphite is considered as organic waste which is treated by the electrolysis process to decompose the waste. Then, Oetami, et al (2006), have researched existing wastes in PSTNT Bandung including reflector waste. This research grouped several radioactive waste materials in PSTNT or formerly known as PTNBR Bandung. This paper also discussed the impact and process of waste disposal because of some upgrading projects in Bandung Nuclear Area. Also, Suwardiyono (2010), in his research carried out the design of the TRIGA Mark II Bandung research reflector waste container. The design calculation method was calculated manually. Daryoko, et al (2011) conducted research for estimating radionuclides calculation on components of TRIGA Mark II Bandung. Specifically, the graphite component of the reflector using the ORIGEN 2.0 computer code.

In 2015 this waste was planned to be removed from a temporary waste pool in Bandung into PTLR-Serpong. The process of designing a reflector waste container is the beginning of a long process of removing this waste into PTLR Serpong. Based on Government Regulation No. 58 of 2015 concerning the radiation protection and transportation of radioactive substances, this process is one of the stages in the process of transferring a radioactive substance. The container design must meet safety standards for workers, the community and the environment based on existing regulations. The container, consists of several parts. The primary part is the wall or shielding from the container.

In contrast to previous researches, this study of reflector shielding container design has been simulated with software. Furthermore, the exposure rate of this waste container is acquired directly from the field. Then, Microshield 7.02 software is used to calculate several data to start the design. MicroShield 7.02 is a software that can help the design of shielding from radioactive material including the waste container. This software has some advantages in terms of simulating the dose rate measurement so that it can be used as a reference before the design is made. This reflector waste requires a container that can reduce the amount of radioactivity for moving this waste into the last storage. It is estimated that the shielding of this waste container will meet the requirements for the III-Yellow type container. The shielding from this container is estimated no more than 5 cm. The type of container will be explained in the theoretical foundation section.

2. Theory
In the calculation of shielding which is part of the reflector waste container using various basic theories about external radiation protection, waste specifications, radioactive waste transportation regulation and category, and software’s features. These are the elaborations of these base theory:

2.1 External radiation protection
The design of this package is based on the principle of radiation protection is justification, limitations, and optimization. Whereas in terms of external radiation protection is more emphasized on the limitation of time, safe distance, and the use of shields. In the case of making a container the same is the case with the use of the principle of shielding where the radiant energy from gamma transmitters or X-rays requires a barrier to absorb the radiated energy. So the energy that comes will be absorbed by the shield and there is some energy that is passed on. For example the intensity of the radiation (Io) or the incoming dose (Do) and the intensity (I) or the dose (D) that is passed on or which is translucent can be formulated as follows;

\[ I = I_o \times e^{-\mu x} \]  \hspace{1cm} (1)

\[ D = D_o \times e^{-\mu x} \]  \hspace{1cm} (2)

where \( \mu \) is the linear attenuation coefficient of the material to gamma radiation and X-rays in units of \( \text{cm}^{-1} \) and \( x \) is the thickness of the half. The following various linear attenuation coefficients of the material in Table 1.
This value can apply to radiation with thin absorbent material. Whereas for sources with beam spreads the equation changes to:

\[ I = B I_0 \cdot e^{-\mu x} \]  

(3)

Where \( B \) is the Build-up factor. The build-up factor is influenced by the type of absorbent material, the thickness of the material, and the radiation energy that surrounds it. In this case, it is necessary or not to use the build-up factor based on the value of \( \mu \) times with the thickness of the material. If the product is more than one then the build-up factor will be used. For example, for a lead shielding \( x = 1 \) cm with attenuation \( \mu = 0.698 \) cm\(^{-1} \) which absorbs energy from Co-60 radionuclides. Then \( \mu x = 0.698 \), while the result of \( \mu x \) must be greater or equal to 1 for the use of the build-up factor. As shown in Table 2.

### Table 2. Build-Up Factor of Lead

| Energy (MeV) | \( \mu x \) (cm\(^{-1} \)) | Build-up Factor |
|--------------|-----------------------------|-----------------|
| 1            | 1.24, 1.42, 1.69            | 2, 2.27         |
| 2            | 1.37, 1.69, 2.26            | 3.02, 3.74      |
| 3            | 1.34, 1.68, 2.43            | 2.75, 5.3       |

### 2.2 TRIGA Mark II reflector waste

For the design of containers such as categories and types that have been determined, dimensions of the waste reflector are required. The dimensions referred to the dimensions as described in the TRIGA 2000 Bandung Reactor Safety Analysis Report book. The reflector is a reactor component that surrounds the reactor core radially. The reflector is made of graphite, with a thickness of 28.4 cm with an inner diameter of 53 cm and a height of 73.3 cm. It is coated with a 0.65 cm thick waterproof aluminum housing. The reflector waste has been activated into several radionuclides where Co-60 is the radioactive radionuclide \( \gamma \) with the greatest activity and is dangerous for external radiation.

Based on research Daryoko, et al (2011) explain that the results of the activation of graphite on the TRIGA Mark II reflector Bandung and its impurities are: C-14, Cl-36, H-3, Co-60, Nb-94, Eu-152, and Eu-152 -154. Furthermore, the results of the activation of the aluminum cap and stainless steel. Although it is unlikely that aluminum can also be activated into isotopes: Mn-54, Zn-65, and Fe-55, while stainless steels become Co-60, Zn-64, Mn-54, Zn-65 and Fe-55. From this study it was concluded that in terms of C-14 and H-3 activity is the most dominant radionuclide, but from radiation exposure Co-60 is the most dominant, because Co-60 has a very high maximum energy, namely 318 keV for particle radiation \( \beta \) and 2 ray radiation energy \( \gamma \), namely: 1.17 MeV and 1.33 MeV. Based on
this information it can be concluded temporarily that x-ray radiation is the dominant radiation emitted by the reflector waste. Furthermore, based on this research Suwardyono (2010) suggests that the size of the container is not too large, and the container is made of concrete and Pb.

2.3 Container and Transportation Index (TI)

Based on Government Regulation no. 58/2015 about Safety of the Transport of Radioactive Substances states that the transport of radioactive substances requires the waste container to be safe and secure. In addition to filling the dimensions of the final storage, the container also must meet the requirements to be safe and secure when it is transported. Based on operational conditions, the package is designed for normal and accident conditions.

a. Normal conditions: Industrial packaging and Type A. Test Type: water spray, free fall, stack and translucent.

b. Accident conditions: packages type B (U) and B (M), type C (air accidents). Test Types: mechanical, thermal, soak, pressurized, translucent, mash, further thermal.

While the general requirements for the package of radioactive material to be mobilized are as follows; design according to weight, contents, and shape. Based on Government Regulation no. 58/2015 the package is divided into several groups and categories as described in Table 3. Transportation Index is calculated based on the dose rate that calculates 1 meter from the container surface.

| Container Category | Transportation Index (TI) | Dose rate on the surface of the container (mSv/h) |
|--------------------|---------------------------|-----------------------------------------------|
| I-White            | TI = 0                    | D ≤ 0,005                                     |
| II-Yellow          | 0 < TI ≤ 1                | 0,005 < D ≤ 0,5                              |
| III-Yellow         | 1 < TI ≤ 10               | 0,5 < D ≤ 2                                  |
|                    | TI ≥ 10                   | D ≥ 2                                         |

2.4 MicroShield 7.02

MicroShield is a software that helps to calculate and analyze the thickness of a shielding or photon or gamma-ray barrier. This software is widely used for several things such as; shielding design, determining the strength of the source from existing radiation measurements. The calculation result could view as a Microsoft Word, Microsoft Excel, HTML, or text files. Results that are saved as any of the first three file types are formatted and color-coded for easy readability. The main results, results with and without build-up, and linear coefficients can all be saved out in the above formats. MicroShield 7.02 can be seen in Figure 1. Inputs needed to make a container or shielding using this software are:

a. Dimensions of sources. In this case the dimensions are related to the reflector dimension that is simplified into annular cylinder type.

b. Source nuclide type. For this design, the source is Co-60 because it is counted as the harmful radionuclide for external radiation.

c. Type of source material. Then, the reflector material is mostly with graphite, some air layer, and aluminum rack.

d. Source Activity.

e. Container / shielding material will be used for the actual case.

After writing down all the data above with a specific case we could sun this software and get data about exposure rate, energy fluence rate in several points that we need.
3. Methodology

This research designs the shielding as part of the container from the reflector waste. It starts with determining all the data that are needed by MicroShield 7.02. The design process was carried out in mid-2015. As noted in the previous sub-chapter, MicroShield 7.02 requires various inputs, one of which is the reflector dimensions and their activities. The dimensions used are based on official sources from the CASNT as a reference. For the calculation of reflector waste activity, measurements were made directly on the field on April 22, 2015.

During the field validation process with the Bandung PSTNT-BATAN Radiation Protection Team, measurements of exposure rates, dimensions, dosage rates, and types of radionuclides in the reflector waste in the Bandung PSTNT Area. Based on field measurements and calculations, the reflector waste activity on April 22, 2015, was 0.557 Ci or 2.13 GBq. The dominant and most dangerous nodule for external radiation is Co-60.

Determination of shielding thickness using MicroShield 7.02 is equipped with input data; first, the desired form of container. Annular cylindrical reflector, the Annular Cylinder-External Dose section is selected. Furthermore, dimension data consists of various sizes for the design to be created. Then shielding thickness was varied for the initial trial of 2 cm and the second trial of 3 cm. After the data is generated then the desired thickness results are obtained by considering the Transport Index of the container later. Then the design is refined by adding a lid and measuring the dimensions of the container. Then the design dimensions are adjusted to the pool size that will storage later. Then, shielding container size, volume, is calculated based on the chosen thickness. After that the projection shielding of the container is drawn a base on the calculated size.
4. Result and Analysis

4.1 Result of MicroShield 7.02 calculate for 2 cm and 3 cm Shield Thickness

With the hypothesis that the container will be built with III-Yellow type and 5 cm maximum thickness, the researchers have considered picking 2 and 3 cm thickness. The reasons are; 1 cm will be too thin, and 4 or 5 cm will consume too many materials. After that with 2 and 3 cm thickness the calculations with MicroShield 7.02 were started. The calculation result is shown in figure 2 for 2 cm case thickness, and figure 3 for 3 cm case thickness, the figures are below.

Figure 2. Microshield 7.02 calculation result for 2 cm lead thickness case.

Figure 3. Microshield 7.02 calculation result for 3 cm lead thickness case.
With a thickness of 2 cm and 3 cm, it is necessary to measure the dosage rate using the build-up factor. After all, data has been completed, the data can be run to determine the type of package. Simulation results from MicroShield 7.02 can be seen in tables 4 and 5.

**Table 4.** Simulation results of measuring exposure rates on the surface from the shielding of the container.

| Source (activity) | Lead Thickness (cm) | Exposure Rate (mR/h) | Dose rate (mSv/hour) | Container Category |
|-------------------|---------------------|----------------------|----------------------|--------------------|
| Co-60 0.557 Ci    | 2                   | 2.573                | 2.401                | III-Yellow         |
|                   | 3                   | 1.378                | 1.286                | III-Yellow         |

The two first things that were observed from the calculation results; first, the dose rate on surface, and secondly, at 1 meter from the surface of the container. The results can be seen in Table 4. In which with 2 cm lead thickness the exposure rate is 2.401 mSv/hour. While for 3 cm thickness, the dose rate becomes smaller at 1.286 mSv/hour. So, to fulfill the requirements of the III-Yellow type, the lead thickness that is used is 3 cm, because this thickness gives the lower result so that it should be safer to take the 3 cm thickness. On the other hand, the thing to be considered is Transportation Index (TI) score. TI score will determine whether the container waste will transport singly or accompany with other wastes. Since the large shape of the reflector waste so that it planned to transport singly. So that the TI should be below. Table 5 can be seen as the results of the measurement of the exposure rate at 1 m from the container surface. TI of 3 cm thick is 189 that smaller than 2 cm’s TI. The result also is shown to us that 3 cm thickness is safer than 2 cm, because the 3 cm’s dose rate and TI is lower than 2 cm.

**Table 5.** Transportation Index calculation results and compatibility with the type of waste reflector container.

| Source and Activity | Lead Thickness (cm) | Exposure Rate (mR/hour) | Dose rate (mSv/hour) | TI | Container Category |
|---------------------|---------------------|-------------------------|----------------------|----|--------------------|
| (Co-60 0.557 Ci)    | 2                   | 33.88                   | 3.16                 | 316| III-Yellow         |
|                     | 3                   | 20.27                   | 1.89                 | 189| III-Yellow         |

Therefore, to fulfill the criteria for a III-Yellow container, the thickness of the lead is 3 cm. This thickness is chosen because the exposure rate is lower than 2 cm. Then, by combining a thick shielding consisting of a base, blanket, tube, and cover, the shielding container will be in the form of a hollow tube with a diameter of 125.8 cm with a height of 82.3 cm. So that the length, width, and height of the container are smaller than the dimensions of the storage pool at PSLAT. These dimensions are smaller than the dimensions of the 3 pools provided (300 x 212 x 600) cm, (250 x 193 x 600) cm, or (360 x 193 x 600) cm. Furthermore, after knowing the lead thickness is 3 cm, the profile of the TRIGA Mark II reactor waste reflector shielding can be calculated as follows:

a. Shape: Annular tubular
b. Diameter: 125.8 cm
c. Height: 82.3 cm
d. Thickness : 3.0 cm
e. Volume : 1,022.0 m$^3$
f. Net weight (reflector weight) : 1,221.5 Kg
g. Shielding of container weight : 1,945 Kg
h. Total weight : 3.167 Kg
i. Material : Lead
j. Container type : Type A
k. Container category : III-Yellow
l. Radionuclide : Co-60
m. Waste activity : 0.557 Ci

The shield of container design drawing based on these dimensions is shown in figure 4 with millimeter unit:

![Figure 4. Technical drawing for container’s shielding](image)

The projection of this design is shown in Figure 5. And Figure 6.

![Figure 5. Projection drawing where reflector is inside of container shielding in vertical cut.](image)

![Figure 6. Projection drawing where reflector is inside of container shielding in horizontal cut.](image)
From research on the design of shielding of container waste of the TRIGA Mark II Bandung reactor with an activity of 0.557 Ci or 0.206 GBq using MicroShield 7.02 software, the dimensions of the container are as follows: tubular container with a total height of 82.3 cm, diameter 125.8 cm, weight of shielding 1,945.13 kg, the total weight of the package 3,176.66 kg. The containers use a 3 cm thick lead. This design meets the standards for category III-Yellow packages with a surface exposure rate of 1.286 mSv/h and the Transportation index is 189 or bigger than 10. These dimensions do not exceed the dimensions of the storage pool at PSLAT and the requirements for the single Yellow packaging category III are fulfilled.

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