Ban. J. Med. Phys., Vol -16, Issue -1, 2025 : 20-23

ORIGINAL ARTICLE

BANGLADESH JOURNAL OF MEDICAL PHYSICS

Journal Homepage: www.banglajolinfo/index.php/bjmp

Analysis of Shield Design Aspects of a Semi-Industrial Co-60 Gamma Irradiation Facility at Institute of Radiation and Polymer Technology of Bangladesh Atomic Energy Commission

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ARTICLE INFO

Article history:
Received : 14 April 2025
Received in revised form : 16 May 2025
Accepted : 30 June 2025
Available online : 1 July 2025

Key words: ^{60}Co, Gamma, Polymer, Irradition, Shielding

doi: https://doi.org/10.3329/bjmp.v16i1.84799
Article Category: Radiation Protection

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ABSTRACT

The aim of this work is to evaluate the existing shield design aspects of a semi-industrial Cobalt-60 Gamma Irradiation Facility for 500 kCi, designed for irradiation of pharmaceutical products, daily food products, and pet/animal foods as well as research and development purposes at the Institute of Radiation and Polymer Technology (IRPT) of the Bangladesh Atomic Energy Commission. Earlier, the initial activity of this facility was 350 kCi and stone based reinforced concrete (SBRC) with a density 2.60 g/cc for specified thicknesses was used to shield the facility for safety to operational personnel and outside public. Due to increasing demand for irradiation services, the IRPT authority decided to raise the activity 500 kCi. For this reason, the shielding design aspects of this facility were needed to be recalculated and checked for safety. This analysis was done using the Point-kernel Shielding Code Micro-Shield 5.05 and public domain Point-kernel Shielding code QAD-CGGP2 respectively considering the radiation worker dose limit 10 µSv/hr and the public dose limit of 0.5 µSv/hr, as recommended by ICRP-60 (1990). The calculated dose rates at different locations around the facility are far below 10 µSv/hr except at positions D1, D4 and D7 inside the source room. No one is allowed to enter the source room when the facility is in ON mode. Therefore, this analysis reveals that the existing shield design aspects of IRPT's Co-60 gamma source room is safe for 500 kCi and ensures radiation safety for both operating personnel and the public.

1. Introduction

The gamma irradiation [1] practice uses the Cobalt 60 radiation to kill microorganisms on a variety of different products. The Cobalt-60 [2] (half-life 5.27 years) emits two high energy gamma photons [3] (1.173 MeV and 1.332 MeV) and is widely used in industrial and medical irradiation facilities for its penetrating radiation and predictable decay.

Between 1 and 2 MeV energy range mass attenuation coefficient is the same for all materials [4] and its value is about 0.55 cm^2/g. So, shielding gamma ray at this energy is material independent. Lead is usually the chosen material for gamma ray shielding, but the above information suggests that high density stone based reinforced concrete (SBRC) is also effective for shielding.

The International Commission on Radiological Protection (ICRP) has recommended the maximum permissible safe dose rate of gamma ray exposure at 0.5 µSv/hr for public and 10 µSv/hr for operating personnel [5]. The Institute of Radiation and Polymer Technology (IRPT) of the Bangladesh Atomic Energy Commission has a semi-industrial Cobalt-60 gamma irradiation facility for irradiation of daily food products (such as spices, chilli, tamarind, coriander, cumin, ginger, garlic, curry masala powder ,dry fish etc,), pharmaceutical products (such as vials, gauge, capsule shell, pharmacy raw materials, in fusion set, syringe, eye drop container, blood collection vial etc,) and pet/animal foods as well as research and development purpose facility. According to ICRP-60, the dose limits are 0.5 µSv/hr for the public and 10 µSv/hr for workers. Given these limits, the IRPT semi-industrial facility, originally designed for 350 kCi, is now planned to operate at 500 kCi, necessitating a re-evaluation of its shielding to ensure radiation safety for both personnel and the public.

2. Methods

2.1 Shield design parameters

The shield design parameters of this facility were calculated from the viewpoint of radiation safety using the Point-kernel Shielding Code Micro-Shield 5.05 [6] and public domain Point-kernel Shielding code QAD-CGGP2 [7]. The partial element density of stone-based reinforced concrete is shown in Table 1 [8-9].

Table 1: Elements and their partial density in Stone Based Reinforced Concrete (SBRC) [8-9]

Element	Stone Based Reinforced Concrete (SBRC and its density 2.60 g/cc) Partial Density (g/cc)
H	0.006401
C	0.011375
O	1.283082
Na	0.038845
Mg	0.007537
Al	0.149427
Si	0.866723
S	0.001162
K	0.086105
Ca	0.080460
Ti	0.003900
Fe	0.060792

2.2 Code for Radiation Shielding Analysis

We used Micro-Shield 5.05 and QAD-CGGP2 point-kernel codes to calculate gamma radiation dose rates around the facility. Point-kernel method [10] is macroscopic approach used for gamma radiation exposure rate calculations. Within this approach gamma radiation propagation is assumed beam-like. Point-kernel technique based on the principles that the radiation received at a detector from a distributed source may be treated as a summation (or integration) of the radiation received from the equivalent number of point sources. That is to say, it is assumed that the individual point sources making up the distributed source do not interact with each other. With a distributed source, the point kernel is integrated over the source volume for each source energy considered. Expressed as an equation, the gamma-ray dose rate, D() at any point due to isotropic emitting S photons of energy E per second per unit volume is [11]

$$D(\vec{r}') = \int_{v} \frac{KS(\vec{r}')B(\mu|\vec{r}-\vec{r}'|, E)\exp(-\mu|\vec{r}-\vec{r}'|)dv}{4\pi|\vec{r}-\vec{r}'|^2}$$

Where, r is a point at which gamma dose rate is to be calculated, is a location of source in volume, (r-) is a distance between source point and point at which gamma intensity is to be calculated, K is a flux-to-dose conversion factor, B is a dose buildup factor, ν is a volume of source region and μ is the total attenuation coefficient at energy E.

2.3 Layout of the Radiation Shield Design for Gamma Irradiation Facility

The figure 1 shows the layout of the semi-industrial Co-60 gamma irradiation facility and the positions of source and detectors (D1-D9). It can be seen that the detectors are positioned to face the most direct beam across the shield.

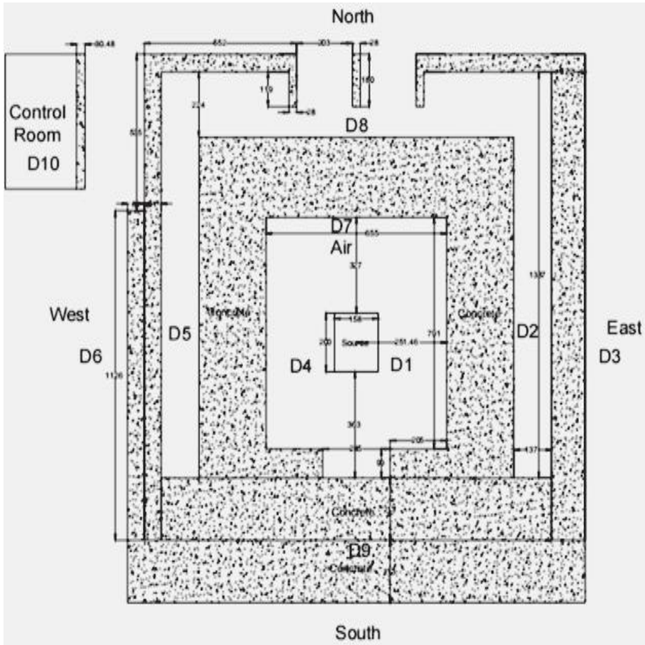

Figure 2: Layout of the radiation shield design for the gamma irradiation facility.

In source room Co-60 gamma source is placed in exact location shown in figure 1. Source is like a cylindrical tube. When the facility is in OFF mode source is placed under the ground. When the facility is in ON condition Co-60 gamma source raised up. The shielding was made of SBRC of density 2.6 g/cc with thicknesses as shown in Figure 1. Control room is located beside the source room and in where facility ON/OFF condition are maintained properly. There is a door between control room and source room. The door is locked and no one is allowed to enter source room when the facility is in ON mode.

For evaluating safety of the facility, the physical positions of the nine detector locations (D1, D2, D3, D4, D5, D6, D7, D8 and D9) have been shown in the said figure. The detectors are positioned to face the most direct beam across the shield. The dose rates are calculated at each of these locations. The roof of this facility was made with a large thickness of concrete. Due to large thickness roof was not considered in this study.

3. Results

The Micro-Shield 5.05 Code and the QAD-CGGP2 code were used to calculate the equivalent dose rates at different locations around the gamma-irradiation facility and the obtained values are shown in Table 2 and Fig. 2.

Table 2: Calculated equivalent dose rates around the IRPT's gamma irradiation facility

Detector Locations	Public Dose Rate limit (µSv/hr)	Occupational Dose Rate Limit (µSv/hr)	Thickness of Shielding Material (cm)	Equivalent dose rate by QAD-CGGP2 Code (µSv/hr)	Equivalent dose rate by Micro-Shield Code (µSv/hr)
D1			251.46 cm (air)	9.213×10^{8}	8.910×10^{8}
D2			251.46 cm (air) + 121.92 cm (SBRC)	2.275×10^{2}	2.168×10^{2}
D3			251.46 cm (air) + 121.92 cm (SBRC) + 137.16 cm (air) + 121.92 cm (SBRC)	2.931×10^{-6}	2.845×10^{-6}
D4			251.46 cm (air)	9.213×10^{8}	8.910×10^{8}
D5	0.5	10	251.46 cm (air) +121.92 cm (SBRC)	2.275×10^{2}	2.168×10^{2}
D6			251.46 cm (air) +121.92 cm (SBRC) + 137.16 cm (air) + 121.92 cm (SBRC)	2.931×10^{-6}	2.845×10^{-6}
D7			322.58 cm (air)	5.751×10^{8}	5.432×10^{8}
D8			322.58 cm (air) + 274.32 cm (SBRC)	4.369×10^{-8}	4.123×10^{-8}
D9			363.22 cm (air) + 213.36 cm (SBRC)	2.720×10^{-4}	2.600×10^{-4}

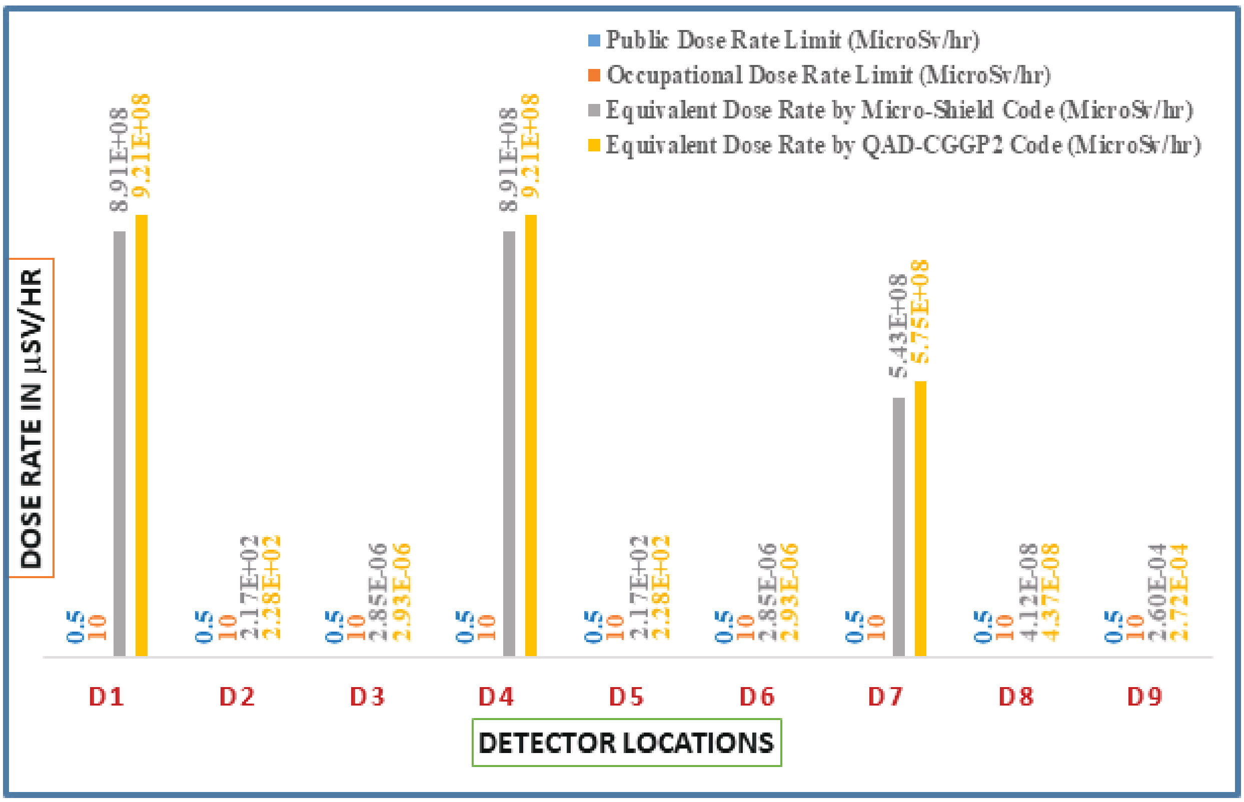

Fig. 2: Comparison among the equivalent dose rates in Micro-Shield code and QAD-CGGP2 code with public dose rate limit and also occupational dose rate limit

The calculated equivalent dose rates at D3, D6, D8 and D9 are well below the 10 μSv/hr worker limit and 0.5 μ Sv/hr public limit. So, these positions are safer for radiation workers as well as public. But D1, D2, D4, D5 and D7 position's equivalent dose rates are much higher than public dose rate limit 0.5 μSv/hr and also operating personnel dose limit 10 μSv/hr. Therefore, these areas are kept secured with locked doors during operation to ensure safety.

4. Discussion

The present analysis deals with the computational shield design analysis of a semi-Industrial Co-60 Gamma-Irradiation Facility at Institute of Radiation and Polymer Technology (IRPT) of the Bangladesh Atomic Energy Commission. Earlier, this facility was designed for a gamma source of initial activity 350 kCi. In view of the recent proposal to install a 500 kCi source, it was necessary to check if the existing shields are adequate from a safety point of view, which was carried out in the present study. The shield design parameters of this facility have been calculated and evaluated based on the occupational personnel dose rate limit (10 μSv/hr) as well as public dose rate limit (0.5 μSv/hr) of the ICRP-60 (1990) criteria with the help of Micro-Shield Code and QADCGGP2 code. The shielding's of specified thicknesses (Figure 1) were made of stone based reinforced concrete (SBRC) with a density of 2.6 g/cc. The obtained equivalent dose rates at D3, D6, D8 and D9 confirm safe exposure levels for workers and the public. But D1, D2, D4, D5 and D7 position's equivalent dose rates are much higher than public dose rate limit 0.5 μSv/hr and also operating personnel dose limit 10 μSv/hr. Thus, D1, D2, D4, D5 and D7 are potentially unsafe if accessed during operation. However, a door is kept locked during operation of the facility and no person is allowed in the source room during exposure of gamma radiation. Proper surveillance should be done at all time to ensure this.

5. Conclusions

This study was carried out based on the computational shielding calculation and evaluation, it may be recommended that the existing shield design of IRPT's Co-60 gamma source room, which was designed earlier 350 kCi, is safer for radiation workers and also public even when the source energy is enhanced to 500 kCi. Therefore, this analysis reveals that the existing shield design aspects of IRPT's Co-60 gamma source room is safe for 500 kCi from the viewpoint of radiation safety to operating personnel and public also.

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