Original Article

A Study on Shield Design Aspects of a Semi-Industrial Co-60 Gamma Irradiation Facility at Gamma Source Division of Institute of Food and Radiation Biology of the Bangladesh Atomic Energy Commission

S Ahmed[1], M. J. H. Khan[*2], A Nahar[3], M F Mortuza[3] and M I Hosan[1]

[1]Department of Nuclear Engineering, University of Dhaka, Dhaka

[2]Reactor Physics and Engineering Division, Institute of Nuclear Science & Technology, Bangladesh Atomic Energy Commission (BAEC), Dhaka

[3]Gamma Source Division, Institute of Food and Radiation Biology, Atomic Energy Research Establishment, BAEC, Dhaka

*Email: jhk_1970@yahoo.com

Abstract

The aim of this work is to investigate the existing shield design aspects of a semi-industrial Cobalt-60 Gamma Irradiation Facility for 100 kCi, designed for irradiation of pharmaceutical products and daily foodstuffs as well as for research and development purposes at the Institute of Food and Radiation Biology (IFRB) of the Bangladesh Atomic Energy Commission. Earlier, the initial activity of this facility was 65 kCi and stone based reinforced concrete (SBRC) of density 2.60 g/cc and specific thicknesses were used to shield the facility for safety to operational personnel and outside public. Due to a large demand for irradiation of pharmaceutical products as well as of daily foodstuffs, IFRB has decided to increase the initial activity up to 100 kCi for this facility. 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 of 10 μSv/hr of the International Commissionon Radiological Protection, ICRP-60, 1990. The corresponding dose limit for public at large is 0.5 μSv/hr. The calculated dose rates at different locations around the facility are far below 10 μSv/hr except in one area. This location is inside the source room. No one is allowed to enter the room when the facility is in the ON mode. However, except one location, positions outside the facility have dose rates about 3 time higher than 0.5 μSv/hr, the dose limit for public at large. Therefore, this analysis shows that the existing shield design aspects of IFRB's Co-60 gamma source room is safe for a 100 kCi source from the viewpoint of radiation safety to operating personnel but not for public at large within proximity of the facility.

1. Introduction

The gamma irradiation [1] process uses Cobalt 60 radiation to kill microorganisms on a variety of different products in a specially designed cell. The Cobalt-60 [2] (half-life 5.27 years) is the most common industrially used gamma radiation source because of its non-solubility in water and simple manufacturing method. As gamma rays are highly penetrating and ionising, personnel involved in the operation and public at large present outside the facility should be safe from gamma radiation. The Cobalt-60 source emits two gamma ray photons (yield ~100%) of energy 1.173 MeV and 1.332 MeV [3]. Between 1 and 2 MeV energy range mass attenuation co-efficient is the same for all materials [4] and its value is about 0.055 cm2/g. So, shielding gamma photons 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 at large and 10 μSv/hr for operating personnel [5].

The Institute of Food and Radiation Biology (IFRB) of the Bangladesh Atomic Energy Commission has a semi-industrial Cobalt- 60 Gamma Irradiation Facility for irradiation of pharmaceutical products and daily foodstuffs as well as for research and development purposes facility. Earlier, the initial activity of the source used in this facility was 65 kCi and SBRC of density 2.60 g/cc of specific thicknesses were used to shield the facility for safety to operational personnel and outside public. Due to a large demand for irradiation of pharmaceutical products as well as of daily foodstuffs, IFRB has decided to increase the initial activity up to 100 kCi for this facility. For this reason, the shielding design aspects of this facility are needed to be recalculated and checked for safety.

The aim of the present work is to investigate the existing shield design aspects of the above semi-industrial Cobalt- 60 Gamma Irradiation Facility for a 100 kCi source, whether it is safe for the operating personnel as well as for public present outside the facility.

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 SBRC is shown in Table 1 [8],[9].

2.2 Code for Radiation Shielding Analysis

The point-kernel shielding code Micro-Shield 5.05 and public domain Point-kernel Shielding code QAD-CGGP2 were used for this study. Point-kernel method [10] is macroscopic approach used for gamma radiation exposure rate calculations. Within this approach gamma radiation propagation is assumed beam-like.

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

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 receivedfrom 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. Expressedas an equation, the gamma-ray dose rate, D(r), 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, r’ is a location of source in volume, (r-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

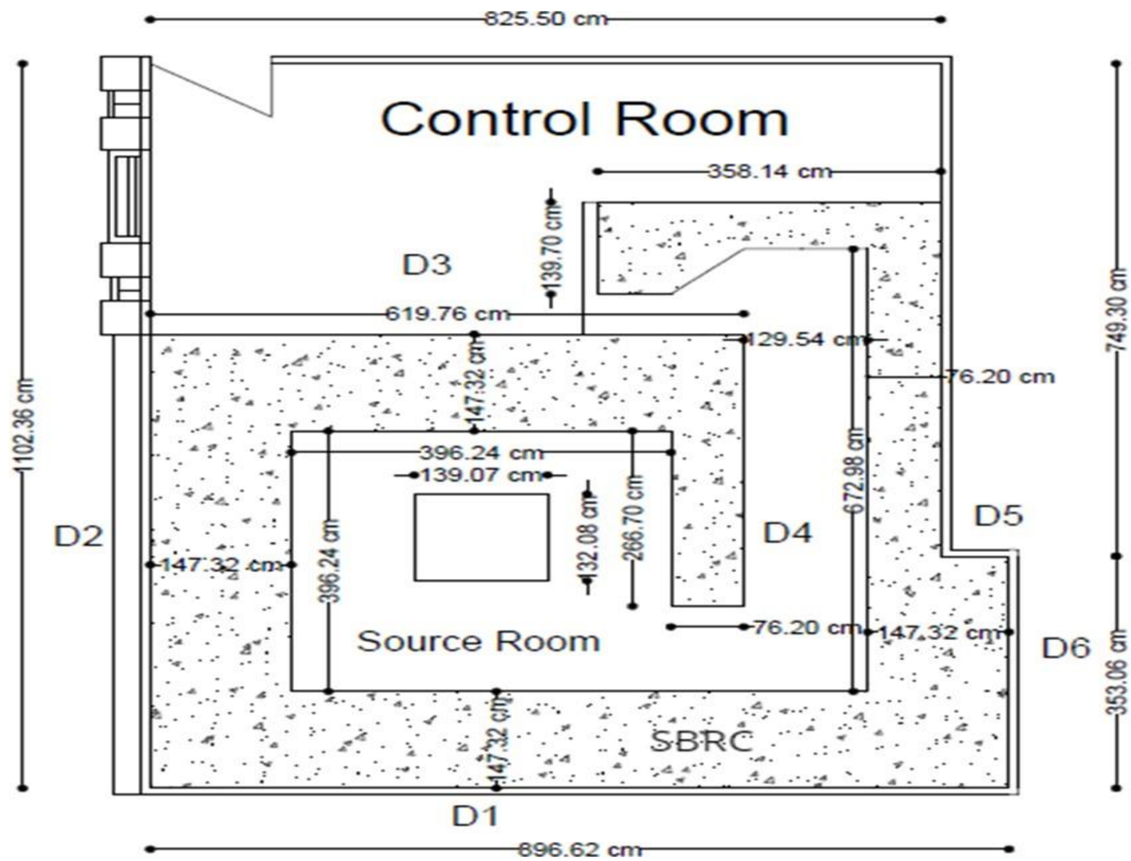

Figure 1: Layout of semi-industrial Co-60 gamma irradiation facility

The layout of the semi-industrial Co-60 gamma irradiation facility is presented in Figure 1 with self-explanatory engineering details. The source is in the form of a cylindrical tube and is placed in the central room. When the facility is in the OFF mode the Co-60 gamma source is kept under the ground in a safe position. When the facility is in the ON condition source is raised up to the source room. The shielding was made of SBRC of density 2.6 g/cc with thicknesses as shown in the figure. Control room is located beside the source room from which the ON/OFF conditions are maintained appropriately. 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 six detector locations (D1, D2, D3, D4, D5 and D6) have been shown in the 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 12 feet thick concrete. Due to its large thickness the roof was not considered in this study.

3. Results and Observations

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

Table 2: Calculated dose rates around the gamma-irradiation facility at IFRB

Detector Locations	Occupational Dose Rate Limit (µSv/hr)	Thickness of Shield Material (cm)	Equivalent dose rate by Micro-Shield 5.05 Code (µSv/hr)	Equivalent dose rate by QAD-CGGP2 Code (µSv/hr)
D1	10	198.12 cm (air) + 147.32 cm (SBRC)	1.62E+00	1.75E+00
D2	10	198.12 cm (air) + 147.32 cm (SBRC)	1.62E+00	1.75E+00
D3	10	198.12 cm (air) + 147.32 cm (SBRC)	1.62E+00	1.75E+00
D4	10	198.12 cm (air) + 76.2 cm (SBRC)	3.82E+04	3.92E+04
D5	10	198.12 cm (air) + 76.2 cm (SBRC) + 129.54 cm (air) + 76.2 cm (SBRC)	4.11E-01	4.51E-01
D6	10	403 cm (air) + 147.32 cm (SBRC)	6.28E-01	6.89E-01

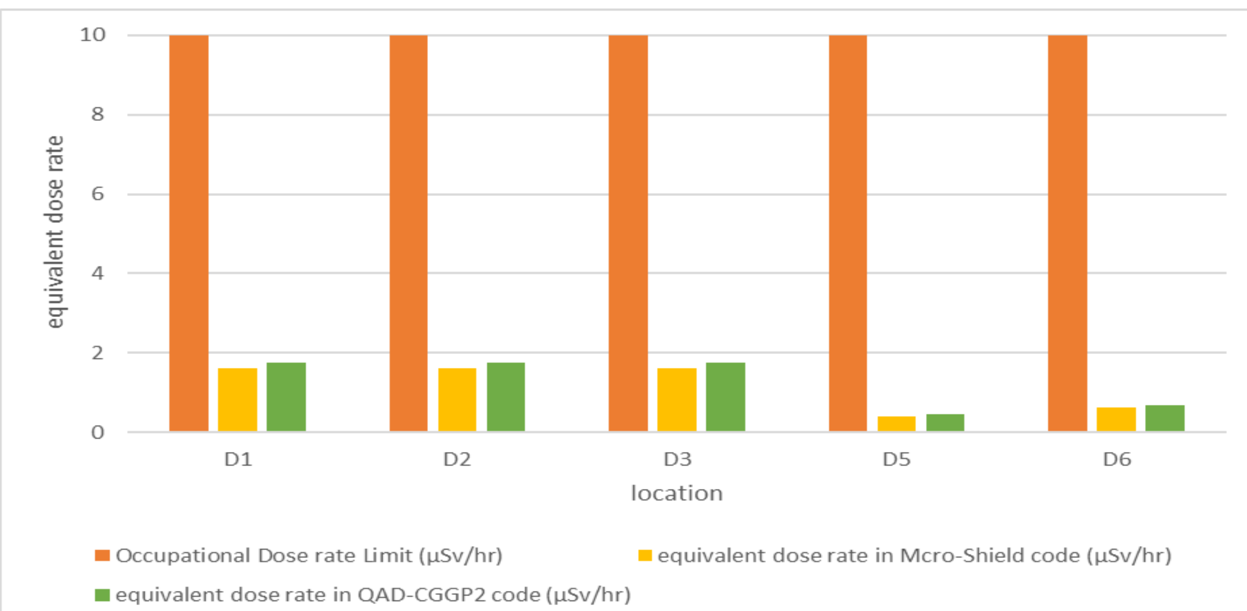

Figure 2: Comparison between equivalent dose rate in Micro-Shield code and QAD-CGGP2 code with occupational dose rate limit without showing D4 region

The calculated equivalent dose rates at D1, D2, D3, D5 and D6 locations (not D4) are found to be far below the radiation workers (occupational) dose limit of 10 μSv/hr in both codes. So, these positions are safe for radiation workers. Out of these only D5 has an equivalent dose rate below 0.5 μSv/hr, the public dose rate limit, the others are above this value. That means these positions are not safe for public at large. The equivalent dose rate at D4 is in the range of 10^4 μSv/hr, which is almost 1000 times higher than occupational dose limit in both codes. Therefore, this position is very dangerous for both workers and public. However, a door is kept locked during operation of the facility and no person is allowed in this location during exposure of gamma radiation.

4. Discussions

The present analysis deals with the computational shield design analysis of semi-Industrial Co-60 Gamma-Irradiation Facility at Gamma Source Division of Institute of Food and Radiation Biology of the Bangladesh Atomic Energy Commission. Earlier this facility was designed for a Gamma source of initial activity 65kCi. In view of the recent proposal to install a 100kCi 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 work. 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 on the public dose limit (0.5 μSv/hr) of the ICRP-60 (1990) criteria with the help of Micro-Shield Code and QAD code. The shieldings of specified thicknesses (Figure 1) were made of stone based reinforced concrete (SBRC) with a density of 2.60 g/cc. The obtained equivalent dose rates at D1, D2, D3, D5 and D6 positions of this facility (Figure 1) were found to be safe for radiation workers. Only D4 position is not safe having almost 1000 times the safe dose. However, this is located after the door between the control room and the source room. So, it is imperative that this door between control room and source room is kept shut, better kept locked when the facility is in the ON mode. At present no personnel is allowed to enter the door during the ON time. Proper surveillance should be done at all time to ensure this.

None of the positions tested except D5 was safe for public exposure. Therefore, care should be taken with regards to this aspect. If necessary, further shielding around this infrastructure should be constructed.

5. Conclusion

Based on this shielding calculation carried out in this work, it may be recommended that the existing shield design of IFRB's Co-60 gamma source room, which was designed for a 65kCi source earlier, is safe for radiation workers even when the source energy is enhanced to 100 kCi, but its surroundings are not safe for the public. Therefore, further shielding should be erected outside this infrastructure for the safety of the public.

References

[1] Gamma irradiation (https://www.steris-ast.com/services/gamma-irradiation/)

[2] Knoll, Glenn F., Radiation Detection and Measurement 4th Edition, Wiley, August 2010.

[3] Eugen A. Preoteasa, Elena Preoteasa and Ioana Suciu. "Atomic and nuclear surface analysis methods: a novel perspective for the characterization of dental composites", Nova Science Publishers, August 2018.

[4] Herman Cember, Thomas E. Johnson "Introduction to Health Physics, McGraw-Hill, Inc., Brachytherapy Facility at DMCH", May 1999.

[5] International Commission on Radiological Protection (ICRP), ICRP publication 60, 1990.

[6] Grove Engineering. Micro-shield 5.05 (Micro-shield for windows), 2000.

[7] V. R. Cain, "A User's Manual for QAD-CG, the Combinatorial Geometry Version of the QAD- P5A Point Kernel Shielding Code" Ne007, Bechtel Power Corp, July 1977.

[8] (https://www.researchgate.net/figure/Chemical-Composition-of-Granite-Sawing-Powder-Waste_tbl1_342029448)

[9] Md. Jahid Hasan, A Computational Shield Design Analysis of Teletherapy Facility at Sher-E-Bangla Medical College Hospital of Barisal, M.Sc. Thesis, B M College, Barisal, October 2012.

[10] I.M. Prokhorets, S.I. Prokhorets, M.A. Khazhmuradov, E.V. Rudychev, D.V. Fedorchenko, "Point-kernel method for radiation fields simulation". Problems of atomic science and technology, 2007, N5. Series: Nuclear Physics Investigations (48), p.106-109. 2007. https://vant.kipt.kharkov.ua/ARTICLE/VANT_2007_5/article_2007_5_106.pdf

[11] Broadhead B. L and Emmett M. B, QADS: A Multidimensional Point-Kernel Analysis Module, 1998.