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Evaluation of Shielding Design of the HDR Brachytherapy Treatment Room at INMP, BAEC, Bangladesh: A Theoretical Calculation

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Abstract: Shielding is important for any type of use of radioactive sources. In HDR (high dose rate) brachytherapy facility, a radioactive source is used to treat the patient. Therefore, shielding design is necessary for brachytherapy treatment room to protect the employees and public from the radiation effect. Brachytherapy treatment room should have sufficient shielding to limit the radiation dose received by other patients, nursing staff, employees and general public present in the surrounding area to permissible levels. In this study, we evaluate the shielding design by manual calculation. Here, we calculate shielding thickness with different positions of the source, so that the dose outside the shielding of the constructed brachytherapy treatment room will not exceed the design (dose) limit. Applying several combinations, we finalize the position of the source. The main objective of this study is to investigate whether our brachytherapy room provides adequate protection for human health. In this study, we calculated the shielding thickness for radiobiological protection for a single Co-60 brachytherapy source of activity 2 Ci. Here, we also define an area for the source for which the theoretical dose rate outside the treatment room will be less than 0.3 mSv/year.

Keywords: Brachytherapy Treatment Room, Design Limit, Instantaneous Dose Rate, Occupancy Factor, Shielding Calculation, Workload.

1 Introduction

Ionizing Radiation has harmful biological effect on living cells. The radiation can come from natural or artificial sources [1,2,3]. Due to radiation exposure, different types of effects e.g., abnormal cell division, permanent modification of cell, cell death etc., may occur [1,2, 4]. It also can affect the next generation of the person who receives radiation [2].

Brachytherapy is one type of radiation therapy techniques for cancer patient with sealed radioactive sources. The source may be placed inside the tissue or very close to the tissue to be treated [5,6]. In the case of localized cancer, high dose to the tumor and relatively low dose to the surrounding normal tissue can be delivered using brachytherapy techniques [6]. Only few minutes are required for treatment delivery using HDR brachytherapy [5,6]. A remote afterloading unit is used in HDR brachytherapy. At INMP, the treatment room has designed and constructed for HDR brachytherapy. For designing a brachytherapy room, some important parameters should be considered such as treatment techniques used, number of patients per day/week/year, types of radionuclides and their activity, time duration per exposure etc. The occupancy factor is also another important factor, should be considered when designing a brachytherapy room. The occupancy factor is related to the amount of time are occupied at the adjacent room/place outside the treatment room. It is different for different types of areas e.g., reception area, laboratories, nurse station, staff rooms, control room, patient's examination room, treatment room, Patient's waiting room etc. [5,7]. As it is a radiation source, the room for HDR brachytherapy unit needs special facilities. To limit the radiation dose received by the other patients, employees and general public present in the surrounding/adjacent area to permissible dose constraint, the thickness of the walls, celling and floor must be adequate [5,6]. The wall thickness also depends on the position of the source. There are some national and international institutions, which deal with the safety and security requirements of radiation related installation. For designing a brachytherapy treatment room, both national

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and international regulations must be followed [5,6,7]. The shielding should be such that, the individual doses should not exceed the acceptable dose limit. The probability of stochastic effects increases with dose. Hence, it is important to provide best available protection and safety measures to limit exposure and number of individuals exposed as low as reasonably achievable [8].

2 Working Principles

2.1 Working Technique

At INMP, a brachytherapy treatment room has been prepared for HDR brachytherapy. In this study, we calculate thickness of walls and ceiling with different positions of the source, so that the dose outside the shielding does not exceed the design (dose) limit. The treatment room is situated in the basement and has more than sufficient concrete thickness, hence we did not calculate the floor thickness. We try to find a position of source for which the constructed walls provide adequate protection during treatment. Applying several combinations, we finalize the position of the source. During treatment, it will be practically difficult to keep the source in a fixed position of the room or in the reference point indicated as source in Fig. 1. Therefore, we also calculate to suggest an area within which any position of the source will provide adequate protection.

2.2 Calculation Techniques

To determine the required wall thickness, a term ‘workload’ must be calculated. The workload for brachytherapy depends on the dose delivered per treatment and the number of treatments.

Workload can be expressed as

$$W = RAKR \times A \times t \times n \dots\dots\dots\dots\dots (1)$$

Where

RAKR is the reference air kerma rate for a source of unit activity,

A is the total activity of the source,

t is the average duration of treatment in hours,

n is the number of treatments per week.

Attenuation of the barrier can be written as

$$B = \frac{P d^2}{W \times U \times T} \dots\dots\dots\dots\dots\dots (2)$$

Where,

P is the design limit or allowed dose per week ($Sv.week^{-1}$) outside the barrier.

d is the distance (m), from the exposed source to the point of interest outside the barrier.

W is the workload, in $Gy.week^{-1}$.

U is the use factor or fraction of the time in which the beam is likely to be incident on the barrier.

T is the occupancy of the area outside the barriers.

The source used in brachytherapy is not collimated, hence it emits in all directions. So, the value of use factor ‘U’ is equal to one. Therefore,

$$B = \frac{Pd^2}{W \times T} \dots\dots\dots\dots\dots\dots (3)$$

From Eq. (1) and (3)

$$B = \frac{Pd^2}{RAKR \times A \times t \times n \times T}$$

The factor ‘$\log\left(\frac{1}{B}\right)$’ gives the required number of tenth value layers (TVL) to achieve the allowed dose outside the barrier. By using this TVL, the required thickness of the barriers was calculated [5].

In this study, we evaluate the safe position of the source for which the design limit will be below 6 µSv/week. which is equivalent to 0.3 mSv/year [5].

The dose at the maze entrance through the maze can be calculated by

$$D_{me} = A \times RAKR \times \alpha \times AR/(d_1{}^2 \times d_2{}^2)$$

Where,

α indicates the reflection coefficient which depends on the types of radionuclide used and angle of incidence.

AR is the irradiated area on the end wall visible from maze entrance, d_1 and d_2 are indicated in Fig. 1 [7].

The limit for Instantaneous dose rate (IDR) is 7.5 µSv/hr [5, 9].

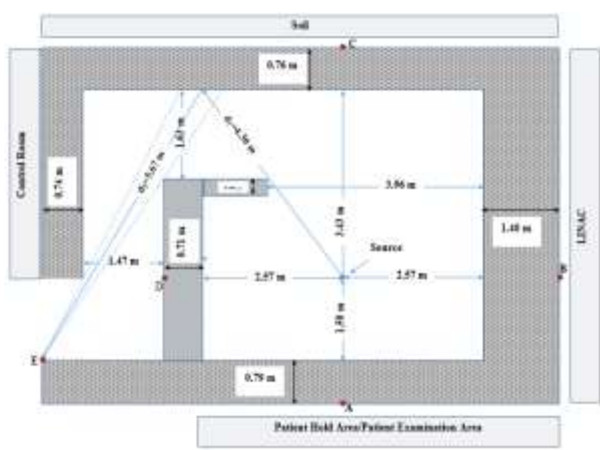

Fig.1: Horizontal cross-section of the Brachytherapy treatment room.

To finalize the position of the source, we calculate the required thickness of the walls at some points, which are in the shortest distance from the source to the outer side of the walls in each side. These points are A, B, C, D. The calculation is done by using occupancy factor 0.5 for the patient hold area/patient examination area and treatment room, and 1 for control room [5,7].

3 Results and Discussion

The required wall thicknesses for the mentioned position of source in Fig. 1 and the constructed wall thicknesses are tabulated below.

Table 1: Comparison between calculated and constructed wall thickness.

Position	Distance from Source (m)	Wall Thickness (m)	
		Required	Constructed
A	2.29	0.67	0.79
B	3.96	0.57	1.40
C	4.19	0.56	0.76
D	3.28	0.67	0.71

From Table 1, it is seen that, the constructed wall thicknesses are sufficient, if the position of the source is in the indicated position in Fig. 1. The thickness of the wall on the 'B' side is extra-large because on the other side of this wall is a LINAC room. The height of the ceiling from the source is 5.18 m (floor to ceiling height is 6.10 m). The required ceiling thickness is nearly 0.51 m of concrete or equivalent which is same in any horizontally shifted position of the source. Here, we have verified that if the source is shifted up to 0.50 m in any horizontal direction from the indicated position in Fig. 1, the doses outside the walls will be limited within the acceptable limit. Hence, the wall thickness of the constructed brachytherapy treatment room is now suitable for a Co-60 source of activity 2 Ci. The dose rate at the maze entrance is satisfactory.

4 Conclusions

Humans are always exposed by ionizing radiation due to naturally occurring radionuclides. Besides, they are now exposed by radiation due to various artificial radiation sources used in medical, industry, nuclear power plant, research and other sectors. Nowadays, the use of radioactive source is increasing in these fields. In these cases, radiation is used for the human welfare. But it will be harmful for human health if it is not used properly. Exposure of human to ionizing radiation can cause harmful health effects. Thus, when a facility related to radiation is designed all the relevant parameter should be considered, so that, we can limit or stop the unwanted exposure. To achieve it, we should design the facility properly considering the position of the source and other parameters. Therefore, we can conclude that, the thicknesses of the constructed walls are sufficient to conduct brachytherapy in the constructed room.

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