METHODOLOGY FOR SHIELDING DESIGN AND EVALUATION IN RADIOTHERAPY FACILITIES

Andrés Enrique de la Fuente Puch*1, Rodolfo Alfonso Laguardia2

1Centro Nacional de Seguridad Nuclear, CNSN (National Center for Nuclear Safety), Calle 28 No 504 e/ 5ta y 7ma, Playa, C.H., Cuba
2Instituto Nacional de Oncología y Radiobiología (Nacional Institute of Oncology and Radiobiology), Calle 29 esq. F, Plaza, C.H., Cuba

Abstract

The Government of the Republic of Cuba has decided to carry out a wide programme concerning the purchase of more than a dozen dual linear accelerators and, also; more than a dozen cobalt-60 units.

Due to the lack of a national methodology for the design and calculation of shielding enclosures for radiotherapy units, the medical physicists from different hospitals began to use different methodologies, e.g. those in:


In some cases this caused the overestimation of the shielding thickness, when applying the values of dose constraints required by the Cuban regulations.

The objective of the present work is to provide the medical physicists, the Radiation Safety Officers and other related professionals with a consistent methodology for the design and remodelation of bunkers hosting radiotherapy units but not using shielding doors.

This work shows the validity of the above mentioned methodology, and the feasibility of designing doorless bunkers for radiotherapy purposes. This methodology is considered to be selfconsistent and therefore no other complementary materials for its application are required.

The experience so far confirms that; entry of realistic input data, and adequate application of sound engineering concepts when using this methodology leads to the achievement of enclosure shielding designs for radiotherapy units that comply with the dose constraints established by the Cuban regulations. Radiation shielding is attained having no over expenses on construction materials and shielding doors.

KEYWORDS: Shielding, radiotherapy, doorless.

* E-mail: andres@orase.co.cu
The ICRP 73 “Radiological protection and Safety in Medicine” [1] in their paragraph 68 outlines “… to avoid oppressive isolation of patients, access to teletherapy equipment will often be through a gated maze rather than an interlocked door. These limitations should be kept in mind, but should not seriously prejudice the level of protection”.

Because of that there is a need for developing a methodology for bunker design accomplishing the levels of protection recommended in the norms in force in the different countries.

The methodology for calculation of the shielding, as indicated in the Safety Reports Series No. 47, "Radiation Protection in the Design of Radiotherapy Facilities” [2], consists basically on the realization of the three following steps:

1. Definition of the design value for the Effective Dose (P) depending of the area to protect,
2. Estimation of the Dose (D) in the point to protect that would be received without shielding,
3. Determination of the Factor of Transmission (B) necessary to reduce D to P.

\[ B = \frac{P}{D} \]

Having B, the number of the Tenth Value Layer (TVL) that will be necessary to assure the required protection, can be determined as \( n = \log\left(\frac{1}{B}\right) \), that is to say the shielding thickness will be given as:

\[ S = n \times TVL \]

It is also possible to determine the shielding thickness from the graphic: ‘Factor of Transmission (B) versus thickness of available shielding’ for each energy and, material to use, as for recommendations in the relevant literature.

It is important to point out that the value of the Effective Dose (P) that should be used for the design of the room (bunker), since the recommendations of the ICRP-60 [3] were approved in 1990, do not coincide with the dose limits as used before that, which, in this ICRP-60 were substantially lowered, due to the introduction of the concept of dose constraint, as an implementation of the principle of optimization, from the concept that in order for an individual, exposed to several practices, to not exceed the dose limits, the dose from the different practices shall be restricted to a fraction of the dose limit.

Due to this change in concept, some renowned experts have outlined that the application of the dose constraints leads to overestimate the shielding thickness if the values for some magnitudes applied in the calculations were taken, as before, with a very conservative approach.

The values of the dose constraints used for the design of the room will depend on the kind of equipment to be installed. That is to say, the dose constraint used for the design of a room for a radiodiagnosis equipment, will be different from the one used for a linear accelerator.

In Cuba the Resolution 34/2001 of the CNSN "Guide for the implementation of the safety rules in the practice of the radiotherapy” [4], states in item 1.1.5 that: "For every installation of Radiotherapy, the following constraints for effective dose shall be applied:

- 10 mSv per year for workers that complete a labor day of eight hours, or the proportional part to this value when the day is shorter,
- 0.5 mSv per year for members of the public”.

Wherever there is a nuclear medicine department adjacent or near a radiotherapy room, it should be taken into account tha t the Effective Dose (P) values taken should not affect the results of the investigations conducted on the patients due to sensibility issues of gamma cameras and other image devices.

It is important to take into account that the point to protect taken as the reference for all the calculations of the barriers is located at 1 ft (0.305 m) on the outsideside of the barrier.
The calculation of the thickness of the primary and secondary barriers can be carried out following the recommendations in the Safety Reports Series No. 47, but is not within the scope of this paper.

For the calculation of the maze having no door, equalization shall be made between the total dose, by the entrance of the maze, and the value of the dose constraint of the area to protect (P), and then determine the necessary length of the maze.

It is important to know that the total dose by the entrance of the maze, has a strong dependence with the energy of the radiation of the equipment to be installed, since if the radiation beam has energies lower than 10 MV this will be determined by the contribution of the primary radiation that is scattered by the patient and the one by the walls, as well as by the head leakage radiation scattered along the maze and the one transmitted to the maze entrance. For beams with energies higher than 10 MV it necessary to, in addition to the contributions previously mentioned, include the one due to the neutrons released mainly by the reaction; \(^4X(\gamma,n)^{\alpha+1}X\), generally known as photoneutrons, and the contribution of the capture gammas produced by the capture of the neutrons in the concrete.

**Calculation of the length of the maze for energies lower than 10 MV**

From the special case analyzed in the Safety Reports Series No. 47, when the axis of rotation of the gantry is perpendicular to the axis of the maze (Figure 1), the total dose \(D_d\) to the entrance of maze is determined by:

\[
D_d = 2.64 \cdot \left( D_p + f \times D_w + D_L + D_T \right)
\]

Where:
- \(D_p\) Dose arising from scatter by patient
- \(D_w\) Dose arising from the primary beam scattered by the wall
- \(D_L\) Dose arising from head leakage scatter to the maze entrance
- \(D_T\) Head leakage transmission to the maze entrance

It is considered that the main contributors to the total dose by the entrance of the maze are: the dose due to the contribution of the primary radiation scattered by the patient (\(D_p\)) and the dose due to the contribution of the head leakage radiation scattered along the maze (\(D_L\)). And for not considering the contributions of the rest of the contributors mentioned earlier, it is assumed that the leg of the maze was properly designed and constructed.

For determining \(d_L\) (long of the maze) and assuming that \(D_p = P\):

\[
P = 2.64(D_{PL} + D_{LH}) = 2.64 \left[ WU\alpha_p(F/400)\alpha_p A_i \left( \frac{1}{d_{sca} d_i} \right)^2 + \frac{L_0 WU\alpha_L A_i}{(d_L d_i)^2} \right]
\]

\[
d_L = \sqrt{\frac{2.64 WU\alpha_i}{P} \left[ \frac{a(F/400)\alpha_p}{\left( \frac{1}{d_{sca} d_i} \right)^2} + \frac{L_0 \alpha_L}{d_i} \right]}
\]
According to the calculations for $d_L$ and for a Co-60 unit, with a workload of 600 Gy/week, assuming a use factor (U) of 0.25 and restricting the area of the door as for workers only, mazes 6.5 meter long are obtained. Id est, if a bunker with a 6.5 m maze is built, the installation of a door is not required.

**Calculation of the length of the maze for energies higher than 10 MV**

The calculation of the total dose in the entrance of the maze ($D_w$), for this case, is determined by the contribution of three components: $D_d$ total dose of photons to the entrance of the maze, $D_c$ the dose for capture gammas, and $D_E$ dose for neutrons.

$$D_w = D_d + D_c + D_E$$

When determining the necessary length of the maze for designing a simple maze (one leg) without a door, in accordance with this methodology, for an accelerator of more than 10 MV, mazes of more than 16 m are obtained, which is not feasible from the constructive and operational point of view, being then required the installation of a proper door.

Therefore there is a need for accelerators of energies higher than 10 MV to have a design of bunkers including mazes of two or more legs as shown in Figure 2.

![Figure 2: Bunker con laberinto de dos framos.](image)

When adding a further leg to the maze, the dose to its entrance is reduced to a third, due to the fact that most of the neutrons will find more interactions with the maze walls before reaching its entrance. It is important to point out that this reduction only takes place if the additional tract (leg) of the maze is long enough; $d_L$ greater than 30 cm, with the purpose of confining the radiation to at least three collisions.

The equations for the calculation of the dose for capture gammas ($D_c$), and the dose for neutrons ($D_E$) for mazes of more than one leg can be obtained from the Safety Reports Series No. 47.

When calculating the length of the leg of the necessary maze to design a doorless bunker, as the one in Figure 2, for an accelerator of more than 10 MV, taking into account that the main contributors to the total dose by the entrance of the maze are: the dose for capture gammas ($D_c$), and the dose for neutrons ($D_E$); as well as that $D_p \equiv P$ the following formula is applied:

$$P = D_c + D_E = W \left[ 5.7 \times 10^{-16} \times \varphi \times 10^{d_L/2} \times 10^{d_c/2} + H \times 10^3 \times (A_c / S_c) \times \left( d_c / d_A \right)^3 \times 10^{d_A/5} \times 10^{d_c/5} \times \left( 1 / 3 \right) \right]$$

Assuming that the Tenth Value Layer of the neutrons in air is 6.2 instead of 5, for obtaining $d_2$:

$$d_2 = -6.2 \log \left( \frac{P}{W \left( H \times 10^{-3} \times (A_c / S_c) \times \left( d_c / d_A \right)^3 \times 10^{d_A/5} \times \left( 1 / 3 \right) + 5.7 \times 10^{-16} \times \varphi \times 10^{d_c/2} \right) } \right)$$

According calculations for $d_2$ for an accelerator of 15 MV, with a workload 600 Gy/week, assuming a use factor (U) of 0.25 and restricting the area of the door as for workers only, $d_2$ 3 meter long are obtained.
CONCLUSIONS

As main conclusion it can be said that the methodology outlined, based on recent recommendations by the IAEA [5,6] and adapted to the conditions in Cuba, contributes a simple but practical method on how to be able to design the maze of a bunker without the necessity of an expensive door.

From the application of the methodology, it was proven that it is possible to design such bunkers for radiotherapy equipment that comply with the dose constraints established in the relevant regulations in Cuba without an undue burden in construction materials and the installation of a door.

REFERENCES