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Maze influence to radiological protection around industrial radiographic sources (Co-60) under 100 Ci

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Abstract

The shielded enclosure design around the gamma radiography facilities under 100 Ci cobalt-60 source was evaluated as well as the maze design and source positions contribution to the dose limitation consistent with the ALARA principle. It was found that the most effective maze type to shield gamma radiations was double (multiple by extension) corners maze type. From discussions on the source positions, practitioners should select the optimizing position from both left or right depending on the length of the maze in the case of single corner type, but never at the central position. The obtained results provided an insightful contribution to the radiological protection in industrial radiography.

1. Introduction

The use of industrial radiography has been wide-spreading rapidly in recent decades. In the early 1950s, it posed serious radiological protection problems. As time goes by, the understanding of radiation interaction with the matter was improved and design principles for industrial radiography installations became a base foundation for radiation protection in this application field. International organizations and national regulatory authorities have though provided requirements to keep radiation exposure within a limit considered to be likelihood safe. Nevertheless, a serious set of problems remain and appeal to attention: many workers in radiographic installations have less understanding of radiation protection principles. For example, radiographic rooms are generally close to heavy metal industries, offices, and other factories with non-ionizing radiation workers. Without enough shielding design, people around radiographic test installation would be needlessly exposed. Engineering barriers (shielding) should be though optimized around radiographic rooms.

Another reason that draws the attention to the shielding design is that only engineering factors as shielded enclosure could be controlled during the designing of installations, while administrative controls could be achieved during the operation of the facility by workers [1]. Factors as workload, structural, accessibility, and economic considerations should be examined to achieve the dose limitation goal [2]. The higher-energy gamma source of cobalt-60 is used in the present study as a source since it is easy to deduct from the higher-energy source the protection around lower-energy gamma source as cesium-137 or Ytterbium-169 [2].

It is a complex task to ensure that the prescribed dose limits are kept under the limit and consistent with the ALARA principle applicable to a country. As the regulation provides rules for the protection of Public areas, the design shall implement the regulation rules. In the Republic of Korea for example, the *Regulations on Technical Standards for Radiation Safety Control, Etc* states that "radiation dose at an area adjoining the boundary of the working place shall be lower than 0.1 mSv/week" [3]. Using the conversion factor for week to days C_{wh} (8h/day x 5 days/week), the value of 0.0025 mSv/h shall be kept as the effective dose rate limit at the boundary of the facility as it is Public area.

This paper discusses a model-engineering factor, shielding (maze type), that contributes to the dose limitation when designing a radiography installation. The appropriate concrete thickness to shield gamma-rays from the source was found prior to the computation of the maze influence to the exposure contribution to the boundary areas. Two different types of mazes were built in view to ascertaining the optimized radiographic room design. The applicability of the maze with a single or double corner(s) is set to cut down the high exposure in front of the door of radiography rooms due to the direct path for radiation.

2. Material and methods

In radiological protection, the engineering barrier as a concrete wall for exclusion area should be preferred to administrative control as human monitoring, which should be under human control permanently with high likelihood of failure due to human errors. This section briefly describes the Co-60 source, the shielding design, and the PHITS Monte Carlo code used for calculation.

2.1. Gamma source of Co-60 under 100 Ci

As a high energy gamma-ray source with a relatively long half-life of 5.27 years, Co-60 is one of the most used sources in industrial radiography. Its decay produces the stable isotope of nickel, Ni-60. The source used was defined as a single source to reflect the situation where only one source is emitting radiation in the facility. It was set as isotropic and dual-energetic point sealed source, with 100 Ci activity that does not decay during the irradiation as it is undertaken in short time scales compared to its half-life. The latest version of Particle and Heavy Ion Transport code System (PHITS ver. 3.10) allows radioisotope type source definition with its real activity [3].

2.2. PHITS Monte Carlo code for calculation

PHITS, a general-purpose Monte Carlo Particle and Heavy Ion Transport code System developed by a collaboration between Japanese institutions and Europe, was used for calculation. The latest version, PHITS 3.10 with several changes allowed the simulation of photon and other particles of interest transport over a wide range of energy. The built code was compiled in shared-memory parallel computing using clusters [2–6].

Among different part of the input code defined for our simulation, the Multiplier section was one of interest. The table of dose conversion coefficients for photon, from ICRP116 was a measured input in this section [9]. The code was pre-compiled on 64 bit Windows computer (i7 X 3.40 GHZ, 16 Go RAM). Finally, 10^9 particles were generated for parallel computing using clusters. The PHITS code was used to find the appropriated thickness of the wall prior to the room design (Fig.1). Data from Table 1 shows that the wall thickness should be set between 110 and 120 cm, and the 120 cm thickness was set for the rest of calculations.

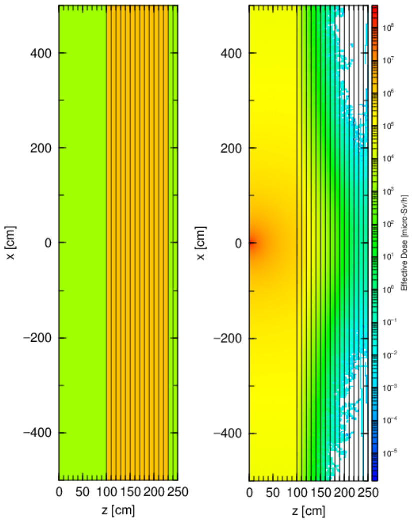

Fig.1. Geometry design for appropriate shielding thickness and distribution of gamma-rays from isotropic Co-60 source.

Table 1: Summary of the effective dose rate related to concrete wall thickness in the closest public area (XYZ = 10cm X 50cm X 50cm). 120 cm or more is the appropriate thickness.

Thickness (cm)	Dose(µSv/h)	Relative error (%)
50	5.228E+03	3.345E-04
60	1.658E+03	5.802E-04
70	5.118E+02	1.901E-03
80	1.596E+02	1.238E-02
90	4.680E+01	4.432E-02
100	1.398E+01	2.164E-01
110	4.175E+00	2.759E-01
120	1.193E+00	2.791E+00
130	3.535E-01	7.734E+00

2.3. Shielding geometry

The most important engineering barrier in the life of an installation is the shielding, that is designed base on the anticipated maximum activity of radioactive sources that will be used in. Significant thicknesses of concrete, lead/iron in the doors, and other shielding material should be set to reduce the radiation level to acceptable limits [2]. In this regard, the geometry built in this research includes concrete walls and maze to offset the direct radiation from the source as shown in Fig.2. Due to long calculation time, the geometry was simplified to access only one side of the facility as the comparison with the full geometry did not show considerable deviations.

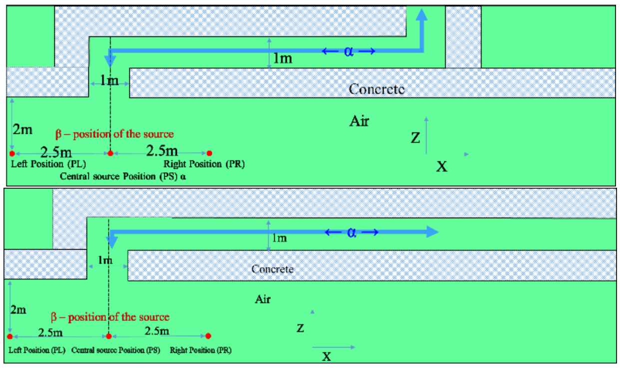

Fig.2. 15 m X 5m designed geometry of a radiographic room with a Co-60 source at three different positions (2m left, center, and 2m right). Two corners maze (top) and single corner maze (bottom) where the three source positions are considered in calculations. The distance parameters α = (1 to 5) describes the path where tally for dose assessment is defined and β describes the source positions β = (-2.5 [left]; 0 [central]; and 2.5 [right]).

The above figures show the consideration of shielding in all adjacent areas as the radiation travels isotropically and their reproduction in PHITS similar to the contents shown in Fig.2. The influence of the above air (skyshine) and scattering from the walls could slightly contribute to the dose rate outside the facility, but those situations are not considered in the present study. Such situations are under investigation for further discussions in the future. The design principle here is based on providing enough shielded enclosure to keep the dose rates out of the facility lower than 2.5 µSv/h, in adherence to the ALARA principle. If not, a large exclusive area should be set, but this part is considered as administrative controls, which are discussed differently.

3. Results and discussion

Installations using Co-60 sources required special design consideration because of their high gamma-ray energy, large size, and heavier devices to be operated. Since the design considerations in the present study are essentially shielded enclosures, the size and shape of the material to be controlled are of great interest. The evaluation of walls thickness for dose limitation shows the effectiveness of concrete wall thickness and the influence entrances on the value of effective dose rate in the boundary areas. Important notice is that the entrance allows easy access to the facility for both workers and objects to be controlled (as larger as possible, at least 1m). So, its design is likely set to provide access capability to lift objects in and out of the radiographic room. The obtained results are presented in Fig. 3 to Fig. 7.

The XY projection of the gamma effective dose rate in the maze base on its length is shown in Fig. 3. As it can be seen, at the exit of the double corners maze, the dose rate is lower than that at the exit of the single corner maze. This is because the photon flux is likely higher in front of the access doors and very high in the maze even though the second maze is longer. This is due to the photon scattering process that propagates in the maze. The first scattered photons are likely to exit the second maze after one interaction (if void considered instead of air) while for the shorter length double corners maze, photons are likely to interact twice at least. If individuals spend time in front of the door of the single corner maze, they are likely to receive a high dose from photon than those staying at the same position in the case of the double corners maze.

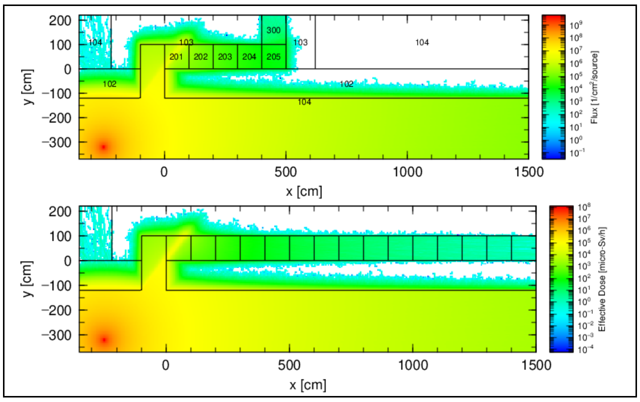

Fig. 3. XY projection of the gamma effective dose rate (μSv/h) in the maze around the radiographic installation. On the top – double corners maze (shortest design). At the bottom – single maze (longer path length).

As can be seen in Fig.4, the position of the source inside the radiographic test rooms is an important factor that contributes to the effective dose rate. At shortest maze length, the left position of the source is the main contributor to the exposure dose due to the gamma source. For longer length mazes, it turns that the left position is the less contributor to the exposure dose. As this result was not expected, it could be explained by the long distance between the exposure point and the gamma source compared to cases where the source is central or on the right side. The central position (β = 0) is always higher and seems to be the worst source position for a radiographic room installation. The variation of the source position allows the optimization of the dose in the boundary of the radiographic installation.

From the Fig.4, it is evident that the central position should not be used as a source position in radiographic rooms with one corner mazes. Instead, the source should be disposed on the left side if the maze length is higher than 7 m and on the right side if it is less than 7 m. These conclusions are drawn for the case where the height of the maze and doors are all equal to 1 m. In addition, if the maze is 7 m long, the effective dose rates for the left and right positions of the source are the same. It should be preferable in this case to set the source on the right side as the standard deviation for the calculation is lower.

The 2.5 μSv/h requirement is achieved for this type of maze in the case of β = -2.5 m from 12 m maze length. It is also achieved for β = 2.5 m from 14 m maze length, which is too long and would be cost-effective.

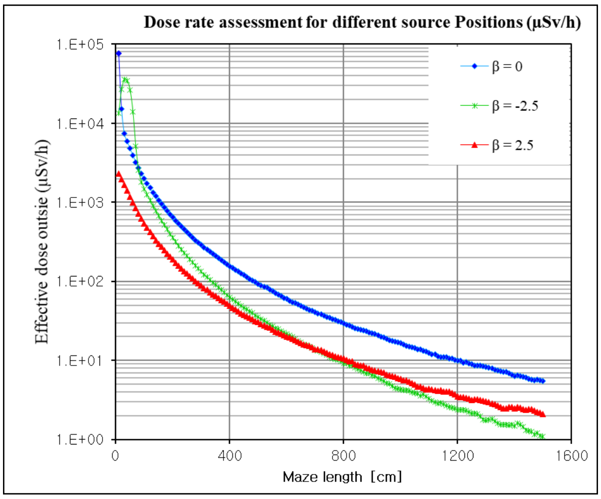

Fig. 4. Effective dose rates in the single corner maze tally around the radiographic installation for different source positions. The source position is described by the parameter β.

The effective dose rates are functions of the concrete wall thicknesses and the length of the maze. Fig.5, Fig.6, and Fi.7 show its dependency to the concrete wall thickness and the dimension of the maze, in the case of double corners maze design. The relative error is less than 10% for all calculation cases presented in this paper.

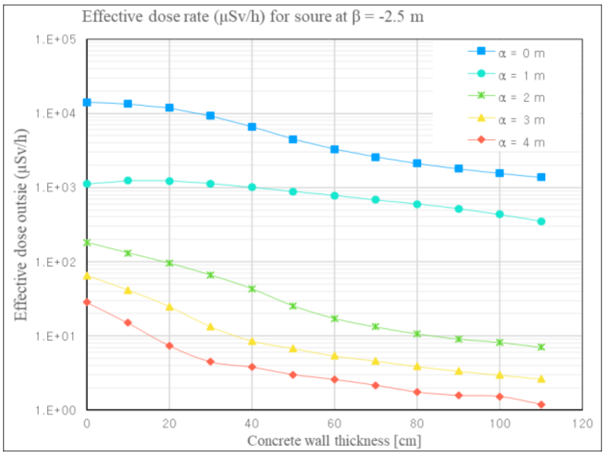

Fig. 5. Effective dose rates in the double corners maze tally around the radiographic installation for β = -2.5 m source position (left side of the entrance). The source position is described by the parameter α = (1 - 4) m.

By positioning the source on the left side of the main entrance door (β = -2.5 m), the values of the effective dose decrease continuously as the maze becomes longer. The reduction factor or the slope of the dose curve decreases slowly for α = 0 and becomes consistent for α = 2 m. Obviously, all α parameters used for calculations do not reduce the effective dose rate to the recommended value of 2.5 μSv/h, except the case α = 4 m. This gamma attenuation was already achieved with 70 cm concrete wall thickness while for α = 3 m, event 120 cm concrete thickness did not cut down the effective dose rate to the desired value. For β = +2.5 m, the right size source position, the recommended value of the effective dose rate is achievable from α = 3 m (>~100 cm concrete wall). This result shows how important it is to set the source position depending on the maze length (Fig.5 and Fig.6).

By positioning the source in front of the main entrance door (β = 0 or central position; Fig.7), the values of the effective dose decrease continuously inversely to the maze length. The reduction factor or the slope of the dose curve is almost constant for α = 0 and becomes consistent for α = 1 m. Only the case α = 4 m reduces the effective dose rate to the recommended value of 2.5 µSv/h and this value is achievable from 100 cm concrete wall thickness.

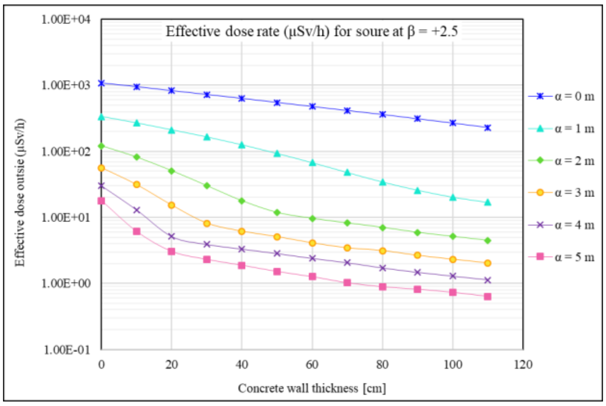

Fig. 6. Effective dose rates in the double corners maze tally around the radiographic installation for β = 2.5 m source position (right side of the entrance). The source position is described by the parameter α = (1 to 5).

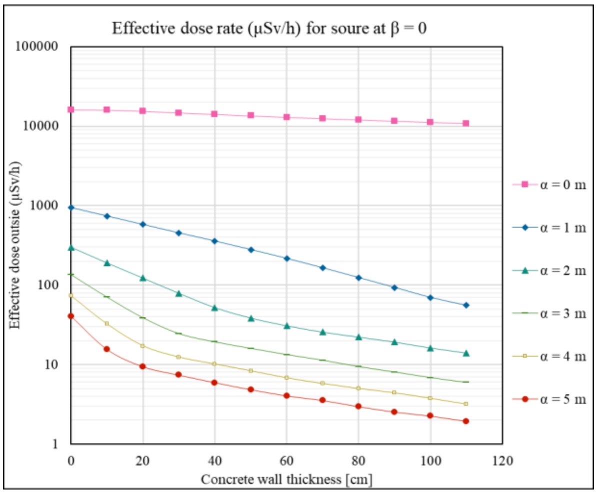

Fig. 7. Effective dose rates in the double corners maze tally around the radiographic installation for β = 0 m source position (central position at the entrance). The source position is described by the parameter α = (1 to 5).

By positioning the source in front of the main entrance door (β = 0 or central position), the values of the effective dose decrease continuously inversely to the maze length. The reduction factor or the slope of the dose curve is almost constant for α = 0 and becomes consistent for α = 1 m. Only the case α = 4 m reduces the effective dose rate to the recommended value of 2.5 µSv/h and this value is achievable from 100 cm concrete wall thickness.

When compare the cases for β = 0; -2.5; and +2.5 m, it is similar to the single corner maze, but with a lower value of the dose for same lengths. The central position of the source (β = 0) is the main contributor to the effective dose rate. This result clearly shows that the best source position to optimize the dose rate reduction in the radiographic room's boundaries is the left / right side, not the central position. In addition, when comparing the result from the double corners maze calculation and that from the single corner, it is clear that the double corner maze is optimum since the maze should not be too long to achieve the ALARA goals of dose limitation.

4. Conclusions

The present study presented a model-engineering factor, shielding, that contributes to the dose limitation when designing a radiography installation. Two factors, the shielding and the maze were assessed in the present study to evaluate their contribution to radiological protection and the optimization of dose reduction around radiographic rooms. According to the ALARA principle, public exposure should be kept < 2.5 µSv/h as this requirement is applicable in different countries as the Republic of Korea. This requirement was used to set the appropriate concrete wall thicknesses and maze types and source positions in the radiographic test rooms. It was found that the most effective maze type to shield gamma radiations was double (multiple by extension) corners maze type. From discussion on the source position, practitioners should determine the source position, that optimize the shielding to reduce the effective dose rate in the boundary areas, from both left or right, but never at the central position. Longer the maze is, expensive the room construction cost should be. It is though recommendable through the present study, to select the design with optimized efficiency.

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