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Comparative study of two methodologies for structural shielding design of imaging facilities

Estudo comparativo de dois métodos para o cálculo estrutural de barreiras em instalações radiológicas

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Abstract

The present study aimed at showing which implications can be found in structural radiation shielding design, depending on the calculation method adopted. Two methods were analyzed: one that considers the sum of thickness contributions, and other that considers the sum of unshielded air kerma contributions. To compare the results, a case analysis was done. A hypothetical radiographic room, which contains a table of exam and a chest bucky, was considered. The thickness contribution method presented the highest results, reaching a maximum relative difference of 85% from the results of the 147 National Council of Radiation Protection and Measurements, and 57% from the unshielded air kerma contributions method.

Keywords: shielding against radiation; radiation protection; air kerma; radiology.

Resumo

O presente estudo teve como objetivo mostrar quais implicações podem ser encontradas no cálculo estrutural de barreiras, dependendo do método de cálculo utilizado. Dois métodos foram analisados: um que considera a soma das contribuições de espessura e outro que considera a soma das contribuições de kerma no ar sem barreiras. Para comparação dos resultados, realizou-se uma análise de caso. Considerou-se uma sala radiográfica hipotética, a qual continha uma mesa para exames e um *bucky* torácico. O método de contribuição de espessura apresentou os maiores resultados alcançando uma diferença relativa máxima de 85% dos resultados do relatório 147 do National Council of Radiation Protection and Measurements, e 57% do método das contribuições de kerma no ar sem barreiras.

Palavras-chave: barreiras contra radiação; proteção contra radiação; kerma no ar; radiologia.

Introduction

In 1925, which was the year of the first International Congress of Radiology, radiation protection practices began to be sketched, mainly, the need of shielding radiation sources to prevent unnecessary exposure to patients and workers[1].

Recently, structural shielding design of radiological facilities intends to protect workers and individual members of the public, decreasing the dose to restricted levels established by national regulations[2,3].

Under this perspective, the National Council of Radiation Protection and Measurements (NCRP) published a structural shielding design methodology in report 147, which became a reference in the area[4-7].

Therefore, this study aimed at comparing two methods for calculating the final shielding thickness, using the 147 NCRP methodology.

Materials and methods

Methodology of the NCRP 147

Equation 1 shows Archer's formulation[8] to calculate the shielding thickness (x).

$$x = \frac{1}{\alpha(W).\gamma(W)}.\ln\left[\frac{B^{-\gamma(W)}+\frac{\beta(W)}{\alpha(W)}}{1+\frac{\beta(W)}{\alpha(W)}}\right] \quad (1)$$

where:

$\alpha(W)$, $\beta(W)$ and $\gamma(W)$ are fitting parameters, which are dependent of the attenuation properties of the considered shielding material and also of the workload spectra (W).

Transmission factor (B) consists of the ratio of the shielded air kerma ($K_{(x)}$) by the unshielded air kerma ($K_{(x=0)}$), as shown in Eq. 2[4,8]. The shielded air kerma is related to the planned restriction of the area concerned, which

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means radiation restriction level (P) corrected by the occupancy factor (T).

$$B = \frac{K_{(x)}}{K_{(x=0)}} = \frac{P}{T}\cdot\frac{1}{K_{(x=0)}} \tag{2}$$

In addition, unshielded air kerma depends on equipment output (K_W^1), workload distribution (W), average number of patients examined in a week (N), and source's distance (d), as indicated in Eq. 3[4,8].

$$K_{(x=0)} = \frac{K_w^{1}.W.N}{d^2} \tag{3}$$

In practice, for the equipment that is used with the X-ray tube directed to more than one position, there are two methods for calculating the required shielding thickness, especially for secondary barriers.

The first method consists initially on calculating the shielding thickness contribution using Eq. 1 for each X-ray tube position. Afterward, these individual thickness contributions are summed in order to find the final shielding thickness.

The second method is operated by calculating the unshielded air kerma contribution, using Eq. 3 for each X-ray tube position. The total unshielded air kerma is obtained summing all individual unshielded air kerma contributions. This value is used to find the transmission factor, which is applied to calculate the final shielding thickness.

Thickness contribution method

Figure 1 schematically shows the thickness contribution method for a radiographic room.

This method uses Eq. 1 to calculate each shielding thickness contribution, using specific workload distributions. For example, Figure 1A shows the use of the X-ray tube for abdominal images, which utilizes a workload W_1, while Figure 1B shows its use for chest examinations, whose workload is W_2.

The final shielding thickness will be the sum of all thickness contributions for the analyzed barrier.

Air kerma contribution method

Figure 2 schematically shows the air kerma contribution method for a radiographic room.

This method uses Eq. 3 to calculate each unshielded air kerma contribution. The sum of these contributions will be used to calculate the transmission factor, B, to finally find the shielding thickness necessary to protect the desired area.

Since α, β and γ are dependent on workload spectra, the sum of all workload distributions, of each X-ray tube positioning, needs to be considered. The resulting values are summarized at the α, β and γ parameters for all barriers, which in NCRP 147 is mentioned as RadRoom (all barriers)[4].

Case study: radiographic room

A case analysis was done in order to compare both methods. The considered facility consisted on a radiographic

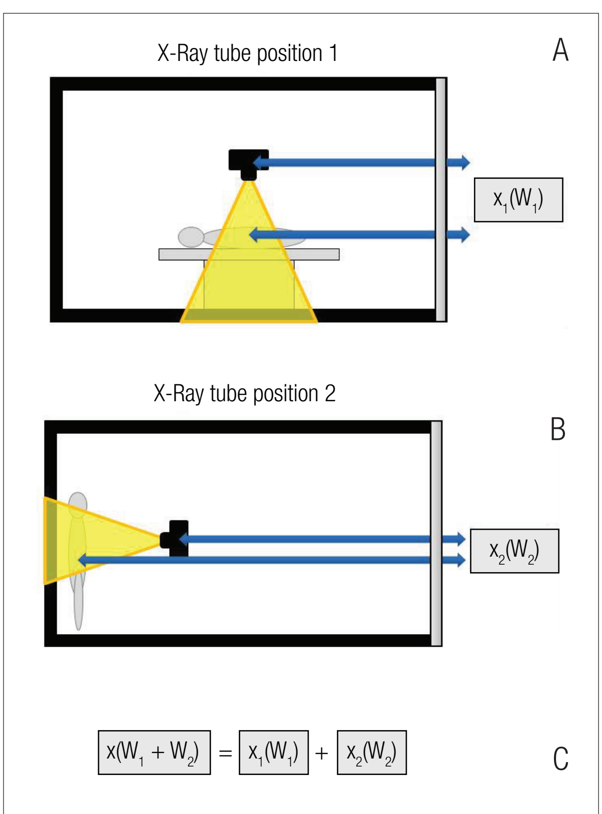

Figure 1. Illustration of the thickness contribution method scheme.

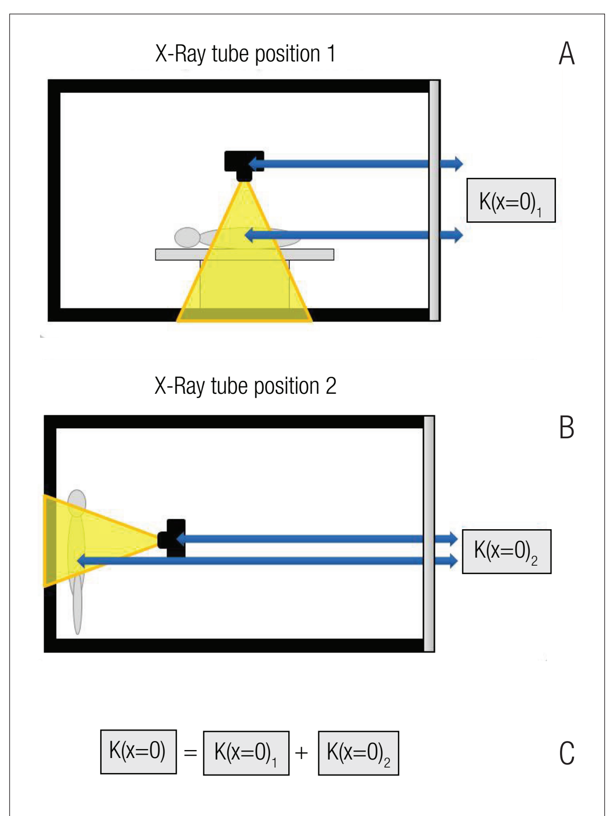

Figure 2. Illustration of air kerma contribution method scheme.

room, which examines 125 patients per week, presented as one of the examples at NCRP 147 (Example 5.3[4]). This hypothetical room was used to evaluate the result differences on the application of the two methods.

Figure 3 shows the X-ray tube positions, which were considered to be used during the room routine, and Figure 4 represents the case analyzed, showing the calculation parameters used.

A computer algorithm was developed[9], and a computer calculation software was used to execute the calculations. Only secondary shielding thicknesses were calculated, since primary barriers calculations for both methods result in equal thickness values.

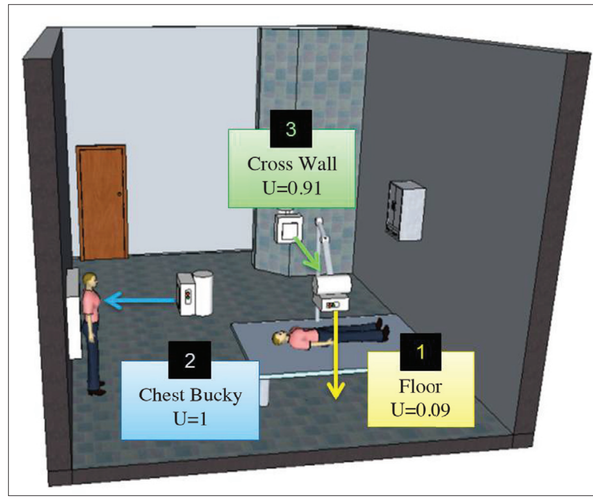

Figure 3. The three X-ray tube positions considered to the case analysis, indicating the respective use factors.

Results

Table 1 shows the shielding thickness results for the radiographic room presented in the Methodology, using the thickness and the air kerma contribution methods. Results of the NCRP 147[4] are also presented to compare the results.

Figures 5 and 6 indicate a comparative analysis of the results, separated by lead and concrete thicknesses, respectively.

Discussion

Table 1 shows that all final shielding thickness, calculated by the thickness contribution method, resulted in higher values when compared to NCRP 147 results, which can also be seen in Figures 5 and 6. This can be explained by the fact that NCRP 147 calculation considers only one X-ray tube position, although the radiographic room presents three ones.

Nevertheless, barriers A, E and F presented lower values compared to those presented in NCRP 147. This is explained by the use of conservative distances by NCRP 147. In barrier A, for example, this publication used a distance of 3 m from the scatter radiation source (patient) to the point to be protected, instead of 4.1 m presented by the architectonical plant.

Therefore, the thickness contribution method also showed the highest thicknesses needed for shielding the room, when compared to unshielded air kerma contribution method. This fact demonstrates that calculating individual thicknesses, and summing all of them in the end of the process represent a final shielding thickness higher than calculated by others methods, such as the sum of unshielded air kerma contributions.

For thickness contribution method applied to the studied radiographic room (Methodology), thicknesses differences reached 0.8 mm of lead and 28 mm of concrete from NCRP 147 results. This corresponds to a relative difference of 62 and 85%, respectively. The magnitude of these differences is mainly due to the distances between the secondary radiation sources from the interest point.

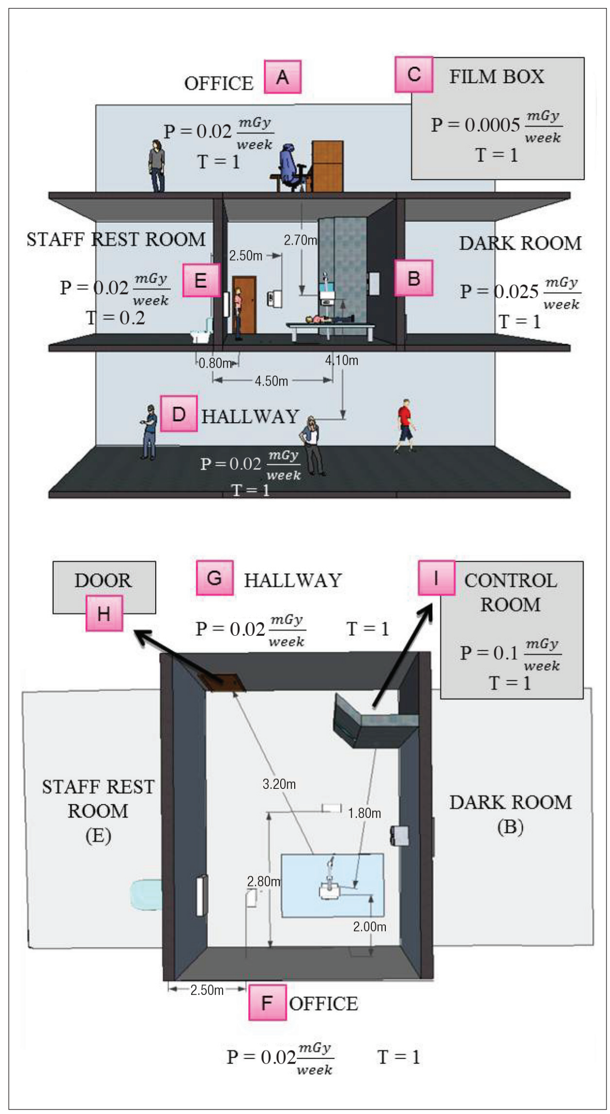

Figure 4. Illustration of the radiographic room used as an example for analyzing the two methods for structural shielding design. Pink squares correspond to the barriers' names.

Table 1. Results calculated by the thickness contribution method, and values presented by NCRP 147[4].

	Barrier	Thickness (mm)		
		Thickness Contribution Method	Unshielded Air Kerma Contribution Method	NCRP 147 results
A	Ceiling	48	36	44
B	Wall around film box	0.7	0.6	0.5
C	Film Box	2.1	2.0	1.3
D	Floor around primary barrier	61	41	33
E	Wall around primary barrier	0.4	0.3	0.4
F	Wall around primary barrier	1.1	0.7	1.0
G	Wall	0.7	0.5	-
H	Door	0.6	0.4	-
I	Control wall	0.4	0.3	0.3

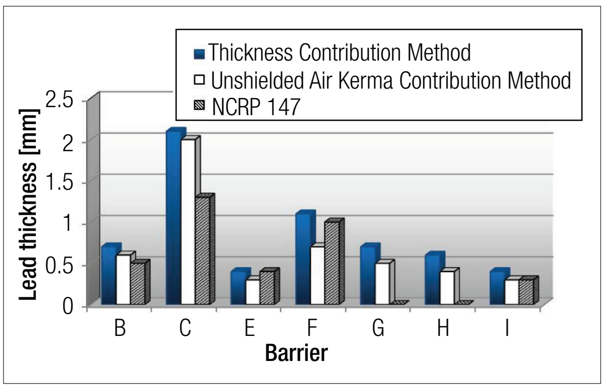

Figure 5. Comparative plot of the lead thickness results of both methods evaluated in this study, and the results presented at NCRP 147[4]. Barriers G and H do not have NCRP 147 results because the publication do not present their shielding thicknesses.

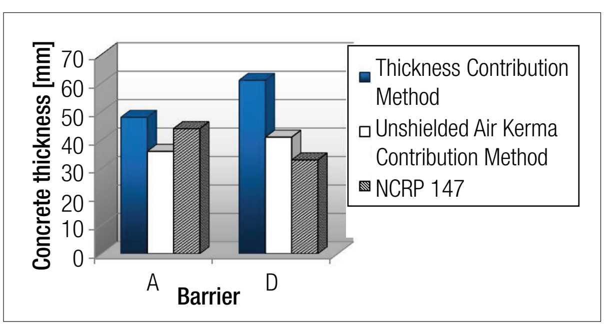

Figure 6. Comparative plot of the concrete thickness results of both methods evaluated in this study, and results presented at NCRP 147[4].

As shorter as this distance is, more evidenced is the resulting thickness difference. This occurs because other contributions of X-ray tube positions were not considered by NCRP 147.

Also, from Table 1, unshielded air kerma contribution method showed, in general, higher results when compared to NCRP 147 values. This fact can also be explained by the previous argument. However, these differences are lower than those presented by the thickness contribution method. This is due to the use of the summed workload distribution RadRoom (all barriers) by NCRP 147.

Conclusions

The present study demonstrated the existence of differences in the final shielding thickness, depending on the calculation method adopted. The results show that the sum of the unshielded air kerma contribution method presented optimized results compared to the sum of the thickness contribution method.

Thickness differences between both methods reached 0.4 mm of lead and 20 mm of concrete for the considered radiographic room (Methodology). These can be relevant at final architectonical and engineering design of a radiological facility.

Acknowledgments

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