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Construction shielding design for medical X-ray imaging equipment

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Abstract: There are analytic methods for designing protective barriers however, they lack sufficient efficiency and considering the NCRP (National Council on Radiation Protection and measurements) reports, designing mechanical protective barrier in order to protect the initial x-ray radiation and absorption of the ray quality of such radiation is different. In this study, computer software was designed to calculate the needed barrier with high accuracy. For proper determination of thickness of the protective barrier, relevant information about curves of radiation weakness, dose limit and other items should be entered. This program was done in windows and designed in such a way that the operator works easily, flexibility of the program is acceptable and its accuracy and sensitivity is high. Meanwhile sometimes shielding is more than what required which lacks technical standards and cost effectiveness. When the application index is contrasting zero, thickness of NCRP49 calculation is about 20% less than the calculated rate done by the method of this study. The multi radiation sources in a single room are considered and non guaranteed radiation of NCRP hypothesis is removed. Difference between the theoretical and calculated rates of this method is $X^2 = 10^{-5}$ which indicates accuracy and high efficiency of this software.

Keywords: Shielding, Diagnostic X-Ray, Attenuation Curve, Building Materials

1. Introduction

These methods reassess shielding calculations in X-ray areas with respect to the methodology of the calculation of the barrier thickness and the number of sources consider in the area. Thus, they generate an overall solution for the cases met at the medical radiation structural design [1].

This report provides an extension of an existing method for the calculation of the barrier thickness required to reduce the three types of radiation exposure emitted from the source, the primary, secondary and leakage radiation, to a specified weekly design limit MPD (Maximum Permissible Dose). Because each of these three types of radiation is of different beam quality, having different shielding requirements, NCRP49 (National Council on Radiation Protection and measurements) has provided means to calculate the necessary protective barrier thickness for each type of radiation individually [2].

However, this report (NCRP49) provides little guidance for the contribution of each of the three types of radiation to the barrier thickness requirement. The medical physicist have to estimate which components of the field are most important to be shielded and how they are to combine, if more than one component is significant to generate a single shielding requirement. In questionable situations, multiple half-value layers (HVLs) of material recommended to be added; by the general "add one half value layer (HVL)" approximation of NCRP49. Since the specified half value layers are those measured at high attenuation, the resultant barrier may be unnecessarily thick [3, 4].

Additionally, barrier requirements specified using the techniques stated at NCRP49, show enormous variations among users. Part of the variations is due to different assumptions made regarding the use of the examined room and the characteristics of adjoining space. Many of the differences result from the difficulty of accurately relating information from the calculations to graphs and tables involved in the calculation process specified by this report. Moreover, the latest technological developments such as mammography are not addressed and attenuation data for three-phase generators, that are most widely used today, is not provided [4, 5].

The design and shielding barriers in diagnostic X-ray departments generally follows the ALARA principle. That means that, in practice, the exposure levels are kept "as low as reasonably achievable", taking into account consideration economical and technical factors. Additionally, the calculation of barrier requirements includes many uncertainties (the workload, the actual kVp used and other items) [6,7,8].

2. Materials and Methods

a. Model Proposed

Some of the variations among shielding requirements determined by various users are resulted from the difficulty of accurately relating information from the calculations, graphs and tables involved in the computation process specified by the NCRP Report 49[2,9]. In order to achieve simplification, Archer proposed a three-parameter model that accurately fit the published transmission data for lead in NCRP49. He also described an approach to account for the contribution of both scatter and leakage radiation [1].

b. Model Description

Each attenuation curve from NCRP49 Appendix D can be described by a curvilinear function, which increases rapidly at small values of lead shielding and then becomes horizontal at the large thickness.

Such behavior was found by Archer integrated to obtain a mathematical representation:

$$K = K_0\left[\left(1+\beta/\alpha\right)e^{+\alpha\gamma x} - \beta/\alpha\right]^{-1/\gamma} \quad (1)$$

Where K is the number of Roentgens per mA-min per week at 1 m, K0 is the value of K with no lead in the beam, X is the thickness of lead in mm and α, β, γ were determined by the use of a modified non-linear least square program[1,7,8].

Application of the model to primary barrier calculations is straight forward since if equation is set equal to the model, the resulting expression can be solved for the thickness of lead required to reduce the weekly exposure at Dpri(Primary dose) to the maximum permissible exposure [1,2,10].

Simplification of the NCRP 49 methods for determining secondary barriers is more difficult since both leakage and scattered radiation must be considered. The scattered radiation barrier is calculated from the equation described at NCRP 49 model. Therefore, setting this equation equal to that of (1), the required barrier thickness to protect for scatter radiation can be calculated[10,11].. For leakage radiation and in order to simplify the procedure for computer calculation, the required number of HVLs (Half value layer) can be related to the transmission factor BLx from the equation:

$$BLx = \frac{Pd_{\sec}^2 \cdot 600I}{WT} \quad (2)$$

The leakage barrier thickness can then be determined:

$$S_L = N \cdot HVL = \frac{-\ln\left\{\frac{Pd_{\sec}^2 \cdot 600I}{WT}\right\}}{\ln 2} HVL \quad (3)$$

The model and the simplification provided by equation (3) could be used to relate the thickness of barriers for leakage and scattered radiation to dsec(distance scatter) [1,12]. The actual exposure from leakage and scattered radiation at any value of dsec can also be determined for a specified barrier. This relation is essential in determining the "exact" secondary barrier thickness required to meet the design limits. The total exposure at a point of interest, Ptot(total exposure at a point), is found by solving equations NCRP and (3) for P and adding them:

$$P_{tot} = P_S + P_L \quad (4)$$

Where PL and PS are the contributions from leakage and scatter radiation respectively. Substitution yields:

$$P_{tot} = \frac{WT}{d_{\sec}^{e}}\left[\frac{\exp\left(-\frac{Ln\,2.x}{HVL}\right)}{600\ I} + \frac{ak_{ux}}{d_{sca}^{2}\left(400\ /F\right)}\right] \quad (5)$$

The above equation is then solved to compute the appropriate thickness of material to make the sum of the calculated leakage and scatter exposures equal to the weekly exposure limit [12, 13].

3. Results and Discussion

Shielding requirements for a radiographic and a chest radiographic unit in combination in the same room. Realistic results. Workload considered being the half for each tube 500 mA min/week for Tube, table number 1 to 6.

Figure (1) shows the excellent fit to the original curves obtained with the model based on the equation (1). For a given value of K, no value of X(Thickness)found to differ by more than 0.03 mm from the original data.

Figure 1: Values generated by the mathematical model of equation (B.1) (open circles) closely approximate the attenuation curves from NCRP 49, Fig.1, Appendix D. (Taken from Archer et al. [1,14]).

One of the advantages of the model is that it provides a concise representation of many different attenuation curves. This greatly simplifies the task of designing a computer program to determine shielding requirements in Tehran University of Medical Sciences. Excellent agreement was found in the shielding requirements for primary barriers calculated by using the above mathematical three-parameter model and NCRP 49 methodology [15, 16].

Moreover, as it has been described analytically, the presented method allows greater accuracy in the computation of secondary barriers. This is due to the fact that the shielding thickness required to reduce the weekly exposure to the design limit, can be precisely determined with no use of the "Add one HVL" recommendation of NCRP 49, which results to over shielding [17].

4. Conclusion

In this study proper determination of required protective thickness for weakening of radiation to the permissible level is proposed. The multi radiation sources in a single room are considered and non guaranteed radiation of NCRP49 hypothesis is removed. Difference between the theoretical and calculated rates of this method is $X^2 = 10^{-5}$ which indicates accuracy and high efficiency of this software [18].

Table 1. *I=4 mA,125 kVp, 1000 mA min/week Radiographic Examinations*

Barrier	P (mSv/week)	Use factor, U	Dpri (m)	Dsec (m)	Dleak (m)
Floor	0.02	1	2.0	1.2	2.0
Ceiling	0.02	0	0.0	1.8	1.0
Barrier 1	0.02	0.5	2.1	1.3	2.0
Barrier 2	0.12	0	0.0	3.0	3.8

Table 2. *Chest Radiographic Examinations I=4 mA,125 kVp, 1000 mA min/week*

Barrier	P (mSv/week)	Use factor, U	Dpri (m)	Dsec (m)	Dleak (m)
Floor	0.02	0	0.0	2.0	2.0
Ceiling	0.02	0	0.0	1.0	1.0
Barrier 1	0.02	1	2.0	2.5	3.0
Barrier 2	0.12	0	0.0	3.0	4.0

Table 3. *Comparison results between these calculated by NCRP 49 and that described in this proposed.*

Barrier	LEAD(mm)	Proposed method(mm)			CONCRETE	Proposed method(mm)		
	NCRP 49	Table	Recp	Grid&cassette	NCRP49 (mm)	Table	Recp	Grid&cassette
Floor	3.0	3.88	3.63	3.07	260.0	280	257	208
Ceiling	2.1	2.43	-	-	155.6	163	-	-
Barrier 1	2.7	3.53	3.30	2.77	240.0	258	235	191
Barrier 2	0.9	.811	-	-	66.8	67.6		

Table 4. *Chest Radiographic Examinations 1000 mA min/week for Tube*

Barrier	LEAD (mm)	Proposed method (mm)			CONCRETE	Proposed method (mm)		
	NCRP 49	Table	Recp	Grid&cassette	NCRP49 (mm)	Table	Recp	Grid&cassette
Floor	2.0	1.77	-	-	148.2	120	-	-
Ceiling	2.6	2.37	-	-	192.6	158	-	-
Barrier 1	3.0	3.69	3.44	2.78	260.0	250	226	177
Barrier 2	0.9	.651	-	-	66.8	52	-	-

Table 5. *Combination of radiographic and chest radiographic examinations in the same room, 1000 mA min/week for Tube*

Barrier	LEAD (mm)	Proposed method (mm)			CONCRETE	Proposed method (mm)		
	NCRP 49	Table	Recp	Grid&cassette	NCRP 49 (mm)	Table	Recp	Grid&cassette
Floor	3.3	3.88	3.64	3.09	260.0	280	257	209
Ceiling	2.9	2.70	-	-	215.0	180	-	-
Barrier 1	3.3	3.93	3.68	3.08	282.4	274	250	204
Barrier 2	1.2	.989	-	-	89.2	77.9	-	-

Table 6. *Combination of radiographic and chest radiographic examinations in the same room.*

Barrier	LEAD (mm)	Proposed method (mm)			CONCRETE	Proposed method (mm)		
	NCRP 49	Table	Recp	Grid&cassette	NCRP49 (mm)	Table	Recp	Grid&cassette
Floor	3.3	3.57	3.33	2.78	260.0	261	237	189
Ceiling	2.9	2.4	-	-	215.0	160	-	-
Barrier 1	3.3	3.62	3.54	2.78	282.4	254	244	185
Barrier 2	1.2	.739	-	-	89.2	60.6	-	-

More realistic results. Workload considered being the half for each tube 500 mA min/week for Tube [19].

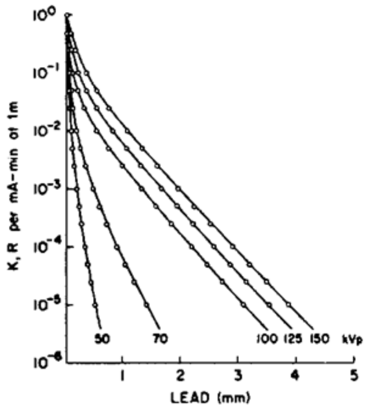

Figure 1. *Values generated by the mathematical model of equation (B.1) (open circles) closely*

Approximate the attenuation curves from NCRP 49, Fig.1, Appendix D. (Taken from Archer et al. [1]).

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