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Shielding evaluation of a typical radiography department: a comparison between NCRP reports No.49 and 147

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Background: Designing and shielding of an appropriate radiography room has been one of the major concerns of radiation scientists since the first decade after the invention of X-rays. Recently, report No.147 of National Council on Radiation Protection and Measurements (NCRP) has been published. In this study the researchers have investigated the effect of new report recommendation on primary and secondary barriers thicknesses in comparison to NCRP 49, and 116 recommendations. ***Materials and Methods:*** To calculate the walls thickness of a conventional radiography room, the workload of a radiography room of a university hospital was determined by recording the number of exposures, mAs and kVp for each patient during six months. Three types of calculations were done: (1) Using NCRP 49 formulations and dose limits (2) Using the NCRP 49 formulations and NCRP116 dose limits and (3) Using the NCRP 147 recommendations. ***Results:*** The estimated workload was 172 mA min wk^{-1} for the studied radiography room which was slightly lower than the workload recommended by NCRP147. The results showed that using the NCRP49 formulation and NCRP116 dose limits, the barriers thickness increases substantially. Moreover, the dose limits were lower in NCRP 147, using the third method. The primary barrier thickness is decreased considerably in comparison to two other methods. For the secondary barrier the results of the two methods (1) and (3) did not differ and remained the same. ***Conclusion:*** Application of NCRP 49 and NCRP116 dose limits for radiography room shielding (second method) overestimated the primary and secondary barriers thickness, significantly. But, applying NCRP 147, not only the new dose limits were considered, but also the cost of primary barrier construction was reduced. **Iran. J. Radiat. Res., 2009; 6 (4): 183-188**

Keywords: *Radiography shielding, NCRP147, NCRP116, NCRP49.*

INTRODUCTION

Protective barriers in radiography rooms play an important role in avoiding staff unwanted absorbed dose. Determination of the thickness of these barriers including primary and secondary type is based on National Council on Radiation Protection and Measurements (NCRP) recommendations [1,2]. Report No.49 has been used as a standard guideline for shielding of radiographic rooms in many countries for about two decades [3,4]. In report No.49 the dose limit for has been determined to be 100 and 10 milli-rontgen (mR) per week, respectively [4,5], in controlled area for radiation workers and general public in uncontrolled areas. Several remarkable changes have been made in dose limits after NCRP No.49 publication. In report No.116 (1993) the dose limits was reduced considerably for both radiation workers and public [6]. The proposed design limits reduced NCRP 49 levels by a factor of ten for controlled areas, and by a factor of five for non-controlled areas. Shielding to the dose limits of NCRP 116 and methodology presented in NCRP 49 generated barriers thicker than those currently in use in diagnostic facilities [6-9]. On the other hand, the sufficiency of these barriers to reduce doses to the lower levels have been proven using evidence from the years of film badge records [6,10,11]. This new approach increased the previously calculated thickness of barriers considerably. In 2004, the report No.147 proposed new guidelines for shielding design in radi-

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ography rooms [2]. The differences between two reports, No.49 and 147, were discussed in details by some articles [4,5]. For occupational exposure, NCRP No.116 recommended that all new facilities should be designed to limit annual exposures to a fraction of the 10 $mSvy^{-1}$ limit implied by the cumulative dose limit. One-half of this fraction is recommended by report No.147; therefore, the annual effective value for individuals was reduced to 5 $mSvy^{-1}$ in controlled areas. For shielding individuals in controlled area, based on ICRP 60 and NCRP No.116 recommendations, shielding designs shall limit exposure of all individuals in controlled areas to an effective dose that does not exceed 1 $mSvy^{-1}$. Thus, the recommendation of NCRP 147 for uncontrolled area is a shielding design goal (in air kerma) of 0.02 mGy per week (1mGy y^{-1}). Additionally, report 147 proposes new guidance for occupancy and use factors based on more realistic estimates. Further, the report No.147 uses the survey data of Task Group 13 by Simpkin. In Simpkin survey, workload in various types of diagnostic settings, the weekly average number of patients, the kVp distribution and the use factors in diagnostic rooms were determined [6,9]. In report No.147, for primary barrier shielding calculation, it is recognized that the primary beam is reduced due to attenuation by the patient, the image receptor, and the structures supporting the image receptor [2, 6].

In many radiography departments the shielding calculations had been based on the report no.49 of NCRP which uses constant workload for all radiography installation and higher dose limits compared to new protocols. The variation of workload and adapting new dose limits makes it necessary to re-evaluate the primary and secondary shielding thickness periodically. Also, applying the new dose limits recommended by NCRP 116 in recent years has necessitated thicker shielding and higher cost for optimizing old radiography rooms as well as new installations. The new NCRP report, No.147 has released to overcome the complexities and problems raised in applying the previous recommendations. A study was designed to compare the effect of adapting new guidelines on optimizing the primary and secondary shielding barriers thickness in a radiography room. In the current study, the thickness of shielding barriers for a typical radiography room was re-calculated based on actual measured workload and using NCRP reports No.49, No. 116 and recently published No.147. The calculation methods and the results were analyzed and compared.

MATERIALS AND METHODS

Workload determination

To have accurate shielding calculation the accurate value of workload is required. So, the exposure techniques for all patients were recorded by radiography staff for six months in a university hospital in Tabriz-Iran. All radiographies were done using a Philips radiography system. To calculate workload, for each patient the number of exposures and techniques including mAs and kVp were recorded. Also, the number of repeated exposures was included in our calculation. Using the collected data, the mean workload in terms of mA min wk^{-1} was calculated.

Geometry of radiography room

The geometry of studied room is shown in figure.1. Walls A and C were primary barriers and wall A was used for stand chest radiography. Walls B and D were secondary barriers, and were considered in the study. The building did not have a basement and second floor.

For primary and secondary barriers calculation using NCRP No.49 the following formulas were used:

$$B = \frac{Pd^2}{WUT} \qquad (1)$$

$$B_s = \frac{P(d_{sca})^2.(d_{sec})^2.400}{aWTF} \qquad (2)$$

In equation (1), B and B_s denote transmission factor for primary and secondary barriers, respectively. P is the maximum permissible dose (currently named dose limit) according to NCRP49 and W, U and T stands for workload, use factor and occupancy factor respectively. In equation (2) for secondary barriers, F denotes field size in terms of cm and α is the fractional scatter at 1 m from the scatterer.

T factor for wall A was 1/16 because the area behind this wall was a part of hospital yard and was not used by public and staff permanently. In our calculations, for wall C the T factor was considered as controlled area and determined 1, because the area was used as patient waiting room and controlled area. The use factor for walls A and C was considered 1 and 1/16 respectively.

Three types of calculations were done: 1) Using NCRP 49 formulations and dose limits 2) Using the NCRP 49 formulations and NCRP116 dose limits and 3) Using the NCRP 147 recommendations. Two sets of calculation were performed using NCRP 49 formulas. First, the recommended dose limits of NCRP 49 were used. Then, using the same formulas, the dose limits recommended by NCRP 116 were used. Third NCRP No.147 was used in calculations. The required thickness of a primary barrier was calculated using the following formula:

Required thickness = NT/Pd^2 (3)

Where N is the total number of patients per week, T represents occupancy factor, P is design goal (mGy/wk) and d is the distance to occupied area (m). For walls A and C, the occupancy factor was considered 1/40 and 1 respectively. The used factors for each method are summarized in tables 1 and 2.

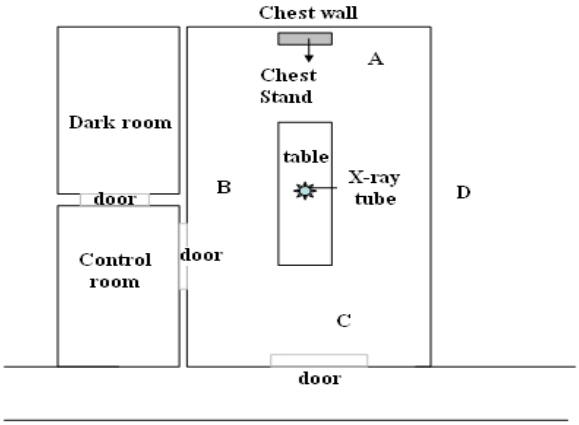

Figure 1. The geometry of the studied radiography room.

Table 1. The data used for determination of primary and secondary barriers thickness using NCRP 49 formula and the dose limits of NCRP 49 and 116.

wall	Type of Barrier	d	d_{sec}	U	T	Barrier's thickness NCRP 49[1]	Barrier's thickness NCRP116[2]
A	Primary	1.4m	-	1	0.0625	2.3mm Pb	3.1mm Pb
B	Secondary		1	1	1	0.3mm Pb	1.0mm Pb
C	Primary	2.9m	-	0.0625	1	0.9mm Pb	1.9mm Pb
D	Secondary		2m	1	1	0.3mm Pb	1.0mm Pb

1- NCRP 49:
P= 1 mGy per week for controlled area
P=0.1 mGy per week uncontrolled area

2- NCRP 116:
P=0.1 mGy per week for controlled area
P= 0.02 mGy per week for uncontrolled area
In this table the NCRP49 formula and real workload were considered. But the dose limits of 49 and 116 were used for calculations.

Table 2. The data used for determination of primary and secondary barriers thickness using NCRP 147 report and real workload.

wall	Type of Barrier	d	d_{sec}	U	T	Wall thickness
A	Primary	1.4 m	-	1	0.025	1.2 mm Pb
B	Secondary	-	2 m	1	1	0.3 mm Pb
C	Primary	2.9 m	-	0.09	1	0.7 mm Pb
D	Secondary	-	2 m	1	1	0.3 mm Pb

RESULTS AND DISCUSSION

The estimated real workload was 172 mA min wk^{-1} for our radiography room. The recommended value of NCRP 147 was 240 and 320 mA min wk^{-1} for an average and busy radiography room respectively. It shows that the recommended workload of NCRP 147 has almost been 28% higher and using NCRP 147 workload may cause over-estimation of required barrier thickness. The distribution of kVp workload could be another important factor in overestimations using NCRP 147. The comparison of the kVp workload distribution of our radiography room, NCRP 147 used distribution and NCRP 49 recommendations are seen in figure 2. As it is seen in figure 2, the more frequent used kVp had a range of 65-70. But, for the kVp spectrum used in NCRP147, the peak of spectrum was located in the range of 85-90. The NCRP 49 had assumed that the entire workload in an installation was performed at a single kVp, 1000 mA min wk^{-1} at 100 kVp. This conservative assumption could cause a considerable overestimation in barrier thickness calculations [7, 9, 12]. Because, the diagnostic workload is spread over a wide range of X-ray potentials, and the dose in air, as well as, barrier transmission were strongly dependent on kVp [9, 13]. On the other hand, in shielding calculations, the distribution of kVp played more important role than the magnitude of the workload, since the radiation level on the other side of a barrier varied linearly with workload; whereas, it varied exponentially with kVp [10].

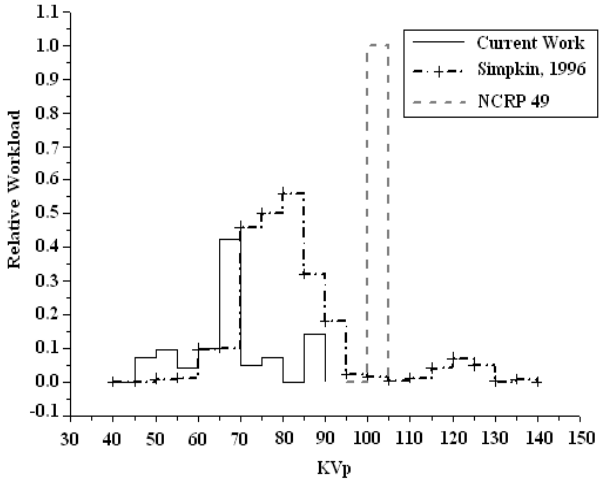

Figure. 2 The comparison of workload distributions obtained from AAPM survey for a radiography room (Simpkin,1996), our studied radiography room and NCRP49 recommendation.

The results of calculations for primary and secondary barriers using NCRP 49 and 116 are shown in table 1. The results of calculations for primary and secondary barriers using NCRP 147 are shown in table 2. The required barrier thicknesses were compared for all walls in figure 3. It can be seen that the lead thickness for primary barriers wall A and C has increased about 0.8 and 1 mm using the new dose limit recommended by NCRP 116. For secondary barriers the required thickness was also increased about 0.7 mm. The thickness increase was resulted from dose limit decrease to one-tenth and one fifth in comparison to NCRP 49 for controlled and uncontrolled areas, respectively. Using NCRP 147 recommendations the thickness decreased for primary barriers considerably as it was evident from table 3. For wall A, chest bucky wall, the thickness was decreased 47% and for wall C, cross-table

wall the amount of decrease was 22%. For secondary barriers, the wall B and D, the thicknesses were comparable to NCRP 49 calculations.

For wall A, chest bucky wall, the significant decrease in required thickness can be partly attributed to the decrease of occupancy factor from 1/16 to 1/40 using the NCRP 147 recommendation. These results were comparable with the results of Tsalafoutas *et al.* in which they considered the attenuation effect of cassette and cassette holder structure in their calculations [13].

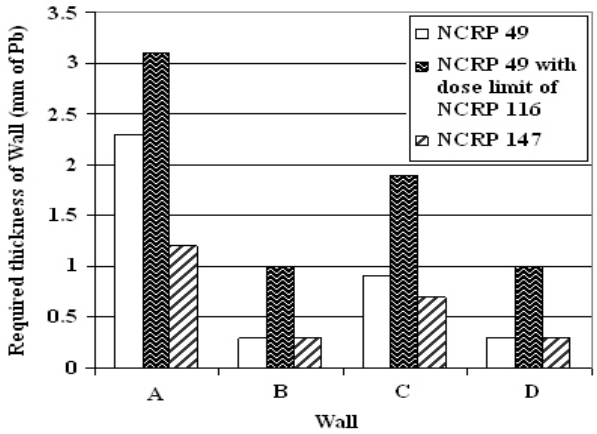

Figure 3. The comparison of the required barrier thickness based on three methods used in the current study.

As it is seen from figure 3, for all secondary barriers (Wall B and D) the thickness does not change and remains constant in calculations using NCRP49 and NCRP 147 recommendations. The same results were seen in the study of Costa and Caldas [11].

Application of dose limits of NCRP 116 and NCRP 49 formulations caused significant overestimation of barrier thickness including primary and secondary types. This overestimation increases the cost of radiographic room shielding and wastes economic resources. In NCRP 147 the use of very practical workloads in the place of 1000 mA min per week is recommended. However, the recommended work load of NCRP 147 could be different in comparison to the workload of a radiographic room. In current research the real workload were estimated. Our calculated work load was about one-fifth of NCRP49 recommended value. But using the dose limits of NCRP 116, the increase in the thickness of barriers was inevitable. Barrier thickness calculations based on NCRP 49 formulation and dose limits of NCRP 116 does not seem very reliable as has been stated by other researchers [5, 7, 9, 13]. To address the problem, NCRP 147 has recommended several corrective methods. In our calculations using NCRP 147, it was seen that although the dose limits were consistent with NCRP 116, the required thickness of barriers reduced to 50% which means that the cost of shielding can be lowered to 50% using NCRP 147. It is consistent with the study by Costa and Caldas [11] on new shielding evaluation method of AAPM Task Group 9 for diagnostic radiology rooms. It was shown that using realistic factors of kVp distribution and photon spectra led to 50% lower shielding cost comparing to those calculated using traditional method based on report No.49 of the NCRP [11].

This paper's results were in close agreement of Simpkin in which they concluded that assuming a single high value for the tube potential can lead to considerable overestimation of barrier thickness requirements [9]. In a model proposed by Tsalfoutas *et al.* [13], the workload distribution across various tube potentials, secondary radiation use factors reduction for primary barriers, attenuation by image receptor hardware and existing building material were taken into account. They found that using the new model, the barrier thickness decreases considerably even with reduction of annual dose limit from 5 mSv year^{-1} to 1 mSv year^{-1} for uncontrolled area. This study showed similar results and it was found that using NCRP49 methodology and new annual dose limit, NCRP 116, the primary barrier thickness could increase even to more than double the values required by NCRP 49 methodology and new dose limits.

CONCLUSION

Shielding calculations was implemented for a radiography room by estimation of real workload and using NCRP49 and NCRP 116 recommendations and the latest recommendation by NCRP 147. The calculations showed that the barrier thickness estimation by means of NCR49 formulation and new dose limits of NCRP 116 significantly overestimate the required thickness of primary and secondary barriers up to 50%. This partly arose from the simplifications and approximations used in NCRP49 formulations and graphs. It seemed more reliable to use more realistic and accurate estimates of the shielding parameters to avoid costly and wasteful over-shielding in diagnostic radiology even with NCRP 147. The study revealed that the application of NCRP 147 recommendations associated with realistic workload not only maintained the new recommended dose limits, but also reduced the cost of room shielding considerably for primary barriers. Finally, the study suggests that applying realistic assumption of workload and NCRP 147 recommendations, the radiography rooms shielded in the past according to NCRP 49 guidelines could still comply with new dose limits with no need to extra shielding for both primary and secondary barriers.

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