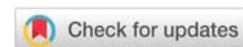


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## Review Article

# Performing shielding calculations for diagnostic radiology based on NCRP Report 147 Methodology

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## Abstract

Structural radiation shielding calculations for diagnostic X-ray facilities is most commonly performed using the recommendations of National Council on Radiation Protection and Measurements (NCRP) Report No. 49 which continues to be the primary guide for diagnostic x-ray structural shielding design for a while. Many changes have occurred over the years that have caused the NCRP Report 49 calculation methodology to become essentially obsolete in that it did not address technology advances in Radiology. The methodology was remedied with the release of NCRP Report No. 147 by enabling shielding designers to, in part, specify effective barriers to diagnostic radiation environments.

The NCRP Report 147 methodology for calculating radiation shielding requirements depend greatly on the shielding design goals (P) where a proposed design limit for controlled and uncontrolled areas is reduced to NCRP Report 49 levels. Further, the methodology most likely uses the concept of "dose constraint" in radiation installations as shielding design goals for the purpose of safety and protection optimization for occupational workers and the public. The previous NCRP Report 49 uses a very conservative approach in the assumption and methodology, which in return yielded with barriers much thicker than what is required in diagnostic facilities.

In this context, Federal Authority for Nuclear Regulation (FANR), the nuclear and radiological regulator for the United Arab Emirates, recently published software which developed by authors for performing radiation shielding calculations based on an algebraic computation model and the given fitting factors provided by NCRP Report No. 147. The International Atomic Energy Agency (IAEA), has taken interest to independently validate the codes of the software; and praise the functionality of the tool. The software performs shielding calculations in an effective, easy, and reliable way while being a cost-effective and a timesaving tool.

## Introduction

Structural shielding design for diagnostic X-ray installations is widely performed following the publications of National Council on Radiation Protection and Measurements (NCRP), specifically Report No. 49 [1] as it has remained the main guidance for performing designs of structural shielding since its issuance. Many changes and advances in technology have emerged in the last decade that gradually rendered NCRP report 49 to be obsolete. Examples of such technological advances include: computerized tomography, mammography and digital imaging that have come into widespread use. Moreover, several reports have analytically examined the conservatism approach of the NCRP Report 49 calculations methodology and the significant changes in the radiology department environment [2]. Further, there has been significant developments in imaging techniques such as screen intensifying and films that

have caused reductions in both radiation exposures and real workload while improving image quality. The revised radiation shielding methodology found in NCRP Report 147 [3] allows shielding designers to identify barriers that are safe and cost effective in diagnostic radiation settings; taken into account new technology, real workload and developments in imaging techniques. This can apply easily to new facilities, as well as, existing facilities and hence, retrofitting of existing structural shielding become inevitable and unavoidable.

## Theoretical and methodology background

In medical diagnostic X-ray imaging installations, the radiation in that environment consists of primary and secondary radiation. Primary radiation is emitted directly from the X-ray source to a primary barrier. Secondary radiation consists of radiation scattered from the patient and other

surroundings objects, as well leakage radiation from the X-ray tube. The primary and secondary radiation exposures depend on the radiation amount produced by the source, distance from the source to the exposed area, time that an individual occupied the irradiated area. Protective shielding between the radiation source and the irradiated area is one that limits the air Kerma from primary or scattered and leakage radiations generated by the radiographic unit to the appropriate shielding design goal or less.

The concepts of radiation shielding calculation found in NCRP Report 147 depend on shielding design goals (P) where proposed design limits are reduced by a factor of ten for controlled areas and by a factor of five for uncontrolled areas. Such dose reductions are proposed in NCRP Report 116 [4]. The methodology for performing radiation shielding calculations depends on the distance (d) to occupied areas and this remains same in both NCRP Reports 49 and 147. The occupancy factor (T) for an area is defined as the average fraction of time that a maximally exposed individual is present. The nominal occupancy factor value has been changed due to the changes in the radiology department environment in revised shielding calculations methodology. NCRP Report 49 suggests a unity value for full occupancy and a minimum nominal value of 1/16 where NCRP Report 147 nominated more a realistic minimum value of 1/40 and kept the fully occupancy value of unity.

Radiation shielding calculations depend on the workload which produces the unshielded Primary Air Kerma at 1 m per workload. In the NCRP Report 147 methodology, the Workload and its distribution (W) has been subjected to significant changes as suggested by AAPM Task Group 9 based on their national survey. The published data [5,6] suggest workload values for various types of medical X-ray modalities.

Traditionally, the conservative assumption of NCRP Report 49 ignores the fact that the medical exposures are performed over a wide spectrum of X-ray kVp and remains performed workload at single kVp that is usually the maximum for all diagnostic procedures. In shielding design, the distribution of kVp is more important than the magnitude of the workload (mA-min) and the same or more significant for leakage radiation. The significant reduction in leakage radiation with kVp is not considered in the single kVp model [2]. Simpkin [5] provides five representative workload spectra to be used as a new method to the shielding design of medical X-ray rooms. The average spectra obtained from the survey of AAPM Task Group 9 provides a more realistic and accurate estimated approach that is representative of the radiation produced in a diagnostic X-ray room.

The use factor (U) is the fraction of the primary beam workload projected toward a given primary barrier. The NCRP Report 147 methodology has made several changes on use factor values based on the survey results of AAPM Task Group 9. These results suggest that the primary beam projected to the non-chest walls are in fact much less often than the fraction previously recommended by NCRP Report 49 [2]. In addition, the X-ray tube can be rotatable, in which case it is possible for the primary beam to be directed to other barriers.

The value of U will depend on the type of radiation installation and the barrier of concern and always assumes a unity value for secondary radiation. The new approach for the use factor should be considered reasonable in shielding calculations.

Typical radiation shielding materials in facilities are lead and concrete. Other materials have been used for shielding purposes such as Gypsum, Steel, and Wood wherein the evidence shows that these materials have proven to be sufficient to reduce doses to required levels thus avoiding costly and wasteful over shielding. Unfortunately, NCRP Report 49 does not provide guidance or attenuation data for such materials. For this reason, it is prudent to use a more realistic and accurate approach for estimates of the required radiation shielding and cost effectiveness. In this regard, NCRP Report 147 provides related data with respect to these materials that may be used as effective shielding materials.

The concept of dose constraint is used to meet facility shielding design goals for the purpose of optimizing radiation safety and protection for occupational workers and the public. It is noted that shielding calculations using conservative dose limits and assumptions allows the calculation methodology presented in NCRP Report 49 to identify barriers that are thicker than those currently in use in diagnostic X-ray facilities. However, redesign of existing thicker shielding as accurate as possible, taken into account the cost of shielding, use of alternative additional shielding materials and apply the ALARA principle when considering monetary cost-benefit requires to obtain an accurate estimation of the equivalent and adequate additional shielding when other shielding materials would be used.

## Discussion and conclusion

The effective and efficient use of shielding materials and the development of optimal design requires a qualified expert for performing either the calculations or for evaluation and reviewing the results. The time and cost required to perform a desirable radiation shielding design must be considered seriously. Therefore, FANR developed software for performing radiation shielding calculations based on the NCRP Report 147 algebraic computation model by using given tabulated data and fitting factors. The software enables the user to enter related parameters via simple user interface, performs the shielding calculation, and provides the user with results for the appropriate shielding thickness required to achieve safety goals and provide adequate protection to occupational workers and public from radiation.

The weekly shielding design goals for controlled and uncontrolled areas are 0.1 (5 mGy annually) and 0.02 mGy (1 mGy annually) respectively. In order to enable local and global users to utilize this software. The Option to choose other regulatory values or enter alternative values based on a desired optimization goal or radiation level in the area of interest is available.

The distance (d) to an occupied area of interest should be taken from the source to the nearest likely approach to the barrier. The distance (in meters, m) should be entered into the

(m) to software, note that the distance should be consider not more than 0.3 m from outer surface of the barrier.

The occupancy factor (T) value used by the software is unity (1.0) for Administrative or clerical offices; laboratories, pharmacies and work areas fully occupied by an individual, receptionist areas, attended waiting room, children's indoor play areas; adjacent X-ray rooms, film reading areas, nurse's stations, and X-ray control rooms. The value of (0.5) is used for patient examinations and treatments room. The corridors, patient rooms, employee lounges, and staff rest rooms are assigning value of (0.2) and value of (0.125) for corridor doors only. Also, the value of (0.05) is assigning for public toilets, unattended vending areas, storage rooms, outdoor areas with seating, unattended waiting rooms, and patient holding areas. The other areas such as Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), attics, stairways, unattended elevators, janitor's closets are using the value of (0.025). The nominal value for the occupancy factor, when assuming that an X-ray unit is randomly used during the week, is the fraction of the working hours in the week that a given person would occupy the area.

The weekly workload (W) of a medical imaging X-ray tube is the time integral of the X-ray tube current over a specified period usually provided in units of miliamperes-minutes. The new methodology presented by NCRP Report 147 defines the normalized workload as the average workload per patient. It is important to distinguish between the number of patients examined in a week (N) and the number of "examinations" performed in a given X-ray room. For clarity, an "examination" refers to a specific X-ray procedure. A single patient may receive several such "examinations" while in the X-ray room and that may involve more than one image receptor.

The radiation shielding designer should be aware that workload information provided by facility administrators should be stated in terms of a weekly number of "examinations", "patient examinations" or "number of patients" examined by X-ray table. The FANR software reflects the NCRP Report 147 methodology and relies only on the "number of patients" exposed in X-ray room per week and average unshielded air Kerma ( $K^{-1}$ ) per patient at 1 m. There is no need for using the conventional methodology to estimate the workload in term of miliamperes-minutes.

The software uses the given value of the use factor for primary beam for the floor or other barriers. This value is 1.0 for chest Bucky, 1.0 for unspecified wall and 0.89 for floor in a radiographic room. The use factor for secondary radiation is always unity.

Finally, the FANR software, "Shielding Calculation for Medical Imaging Installation", uses an algebraic computation model, tabulated data and fitting factors found in NCRP Report No. 147 for shielding thickness  $x_{barrier}$  for primary and secondary according. Equation (1) and equation (2) respectively illustrate the mathematical computation using given tabulated fitting factors Alpha, Beta, and Gamma.

$$x_{barrier} = \frac{1}{\alpha\gamma} \ln \frac{\left(\frac{NTUK^{-1}}{Pd^2}\right)^\gamma + \frac{\beta}{\alpha}}{1 + \frac{\beta}{\alpha}} \quad (1)$$

$$x_{barrier} = \frac{1}{\alpha\gamma} \ln \frac{\left(\frac{NTK^{-1}}{Pd^2}\right)^\gamma + \frac{\beta}{\alpha}}{1 + \frac{\beta}{\alpha}} \quad (2)$$

The FANR software enables the user to enter the related parameters via a simple user interface. It performs the shielding calculation and provides the user with the result for an appropriate shielding thickness required to achieve desired safety goals that would provide adequate protection to occupational workers and the public from radiation [7-9].

The corrections or additions after facilities are completed and existing are usually expensive and most difficult. Therefore, obtain as accurate as possible the equivalent and adequate shielding required when another shielding materials would be used. The relationship between deferent shielding materials thickness (concrete, lead, steel, Plate Glass and Gypsum) has been obtained for wide spectrum of X-ray modalities at diverse setting and assumption. In addition, a conservatively safe approach in specifying radiation barriers has been applied. The obtained relationship which representative by the thickness of concrete (mm) to thickness (mm) of lead, Iron, Glass, and Gypsum were 70, 7.3, 0.96, and 0.33 respectively.

The shielding is the most effective element in X-ray design where usually there are some limitations on time and distance due to nature of diagnostic procedures. The actual dose values to individuals may less than dose values due to a number of conservative assumptions made in the calculation such as ignoring attenuation by the patient and image receptor, overestimated of the workload, occupancy and field size used. In addition to assume that the staff are always in the most exposed place of the room, distances are the minimum possible and leakage radiation is the maximum all the time.

Note: The software (version 1.1) is available on Federal Authority for Nuclear Regulation Web Page:

[https://www.fanr.gov.ae/en/services/others/shielding\\_calculation](https://www.fanr.gov.ae/en/services/others/shielding_calculation)

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