# EG0800212
# Shielding of Medical Radiation Facilities – National Council on Radiation Protection and Measurements Reports No. 147 and No. 151

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## ABSTRACT

**The National Council on Radiation Protection & Measurements of the United States (NCRP) has issued two reports in the past 18 months that provide methods and data for designing shielding for diagnostic radiological imaging and radiation therapy facilities. These reports update previous publications on this subject with revised methods that take into account new technologies, results from measurements and new data that have been published in the last 30 years. This paper gives a brief summary of the contents of these reports, the methods recommended for determining the shielding required and the data provided to aid in the calculations.**

***Keywords*: *accelerator***, *barrier, design, imaging, shielding, therapy, x-ray*

## INTRODUCTION

The National Council on Radiation Protection & Measurements of the United States (NCRP) published two reports, No. 49 in 1976 and No. 51 in 1977, which have been the primary guidance documents for shielding design of medical radiation facilities for 30 years. Because of the lack of information about the use of radiographic and therapeutic equipment and little information about the shielding effectiveness of construction materials, many conservative assumptions were made that resulted in thicker shielding than was needed in many cases. Since that time there have been changes in technology in both diagnostic imaging and radiation therapy. New information has been published on the use of various imaging techniques and the shielding effectiveness of materials.

For these reasons the NCRP published two new reports within the last 2 years to bring their design recommendations up-to-date. The first is Report No. 147, Structural Shielding Design for Medical X-ray Imaging Facilities, November 2004 (Revised March 2005)[1)]. The second is, Report No. 151, Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-ray Radiotherapy Facilities, December 2005[2)].

The two new reports present more detailed methods for shield design that are specific for the technology and use patterns of the equipment and the clinics. Today computerized tomography (CT) is an important imaging technique and intensity modulated radiation therapy (IMRT) is increasingly used in cancer treatment.

Both of these technologies require different considerations for shielding than those for the prevailing imaging and therapy technologies in 1977. Also, a large amount of information has been collected and published on the patterns of use of imaging and therapy equipment.

This allows the designer to apply usage values that are smaller than the default maximum values recommended in the guidelines of the earlier reports. The following sections briefly describe the contents and some of the methods recommended in these two reports.

2. Report No. 147

Report No. 147 contains sections that discuss:
- Fundamentals of shielding for medical x-ray imaging facilities,
- Elements of shielding design,
- Computation of medical x-ray imaging shielding requirements,
- Examples of shielding calculations,
- Radiation protection surveys,
- Appendices containing the data necessary for the calculations.

Early in the report assumptions are stated that result from insufficient information about certain factors that could reduce the amount of shielding required. These assumptions result in a conclusion that by using the methods presented in this report the shielding specified will almost certainly result in measured radiation doses that are less that the design goal. The assumptions are:
- attenuation of primary beam by patient is neglected,
- perpendicular incidence of the radiation is assumed on the shielding walls,
- presence of materials in path of radiation other than specified shielding material is ignored,
- leakage radiation from x-ray equipment is assumed at the maximum value allowed by regulation,
- calculations yield conservatively high values of scattered radiation,
- occupancy factors are generally lower than recommended,
- because lead shielding is supplied in standard thicknesses, the thickness used is usually greater than required,
- the actual distance from the shielded wall to a potentially exposed person is usually greater than the minimum distance assumed (0.3 m).

The types of imaging facilities considered in the report include radiographic, fluoroscopic and mammography installations both permanent and mobile, dedicated chest installations, CT installations, bone mineral equipment, interventional, dental and veterinary facilities.

Shielding materials include sheet lead, gypsum wallboard, concrete, plate glass, lead glass and lead acrylic. Doors, windows, penetrations and construction standards are all discussed. Planning, project development and facility design recommendations are made to avoid unnecessary exposure of patients and staff.

Details of computation of shielding requirements include recommendations for setting the design goals, occupancy and use factors and workload. A new concept introduced is the workload distribution, which is based on many observations of the use of imaging equipment for different diagnostic procedures. This allows the designer to base the shielding requirements on actual usage patterns instead of assuming that all equipment use is at the maximum kVp. An example is shown in **Fig. 1**.

Recommendations include computation methods for primary and secondary barriers, including shielding provided by image receptors and the contributions of

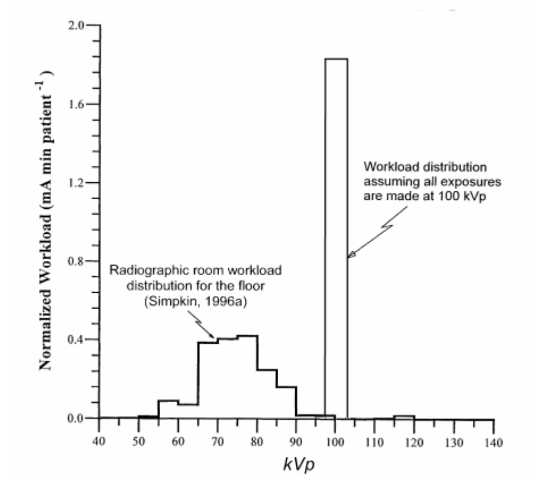


**Fig. 1 Workload distribution for use with radiographicequipment only.**

leakage and scattered radiation. Many detailed examples are provided for determining shielding requirements for specific imaging rooms, such as cardiac angiography, general radiographic rooms, combined radiographic and fluoroscopic rooms and CT.

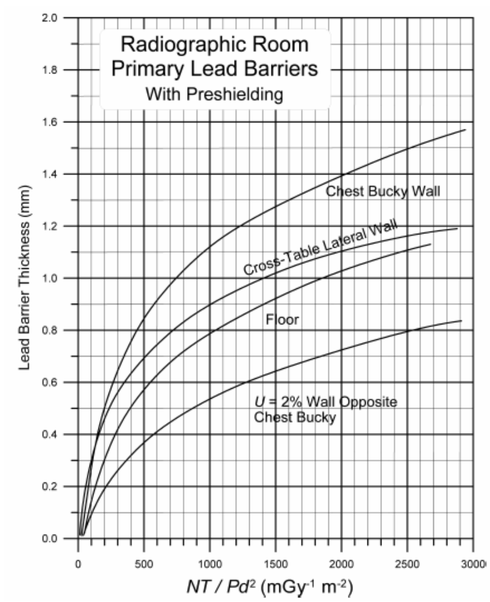


**Fig. 2. Lead barrier requirement as a function of the number of patients (N), occupancy factor (T), design dose (P) and distance (d) from the source to the occupied area. U is the use factor for the wall opposite the chest Bucky.**

As an example, **Fig. 2** gives a plot of the required lead thickness for primary barriers as a function of weekly dose to the occupied area for a general radiographic room. The required thickness is determined by the number of patients, N, the occupancy factor for the area being shielded, T, the design goal for weekly dose, P, and the distance between the x-ray source and the occupied area, d.

3. Report No. 151

Report No. 151 contains sections that discuss:

- Calculational methods
  - Primary & secondary barriers, doors & mazes
  - Laminated barriers
- Workload and use factor
  - Conventional & special procedures
- Structural details
- Special considerations and equipment
  - Skyshine & Groundshine Radiations
  - Side-Scattered Photon Radiation
  - Activation
  - Ozone Production
  - Tomotherapy
  - Robotic Arm
  - Dedicated Intraoperative-Radiotherapy Units
  - Cobalt-60 Units
- Examples of shielding calculations

Details are given of the methods for determining primary barrier thickness including consideration of the beam width at the barrier and the use of laminated barriers consisting of concrete and iron or concrete and lead. Secondary barrier thickness includes shielding for leakage radiation and radiation scattered from the patient. Entry maze and door design are discussed in detail, including methods for estimating the scattering and transmission of photons and neutrons through the maze (**Fig. 3**). The various distances, d, and wall areas, A, are used to estimate different scattering components of the radiation field at the entrance. There is a much more detailed analysis of neutron scattering and transmission than in the previous report, and gamma rays produced by neutron capture processes are included in the door shielding consideration. Methods for analyzing laminated barriers of concrete and iron or lead for neutron transmission are also discussed.

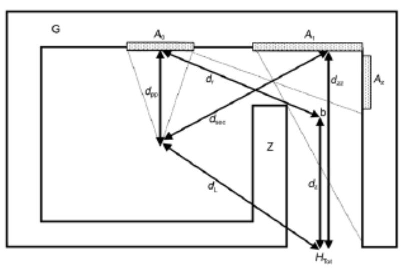


**Fig. 3 General room layout for definition of parameters used in maze door shielding.**

Workloads and use factors are different for conventional therapy techniques and some of the special treatment techniques that have been introduced. Typical use factors for a dual energy therapy unit are shown in **Fig. 4**. This diagram gives the percentage of time the primary beam is directed into a given 45° segment of the full rotation.

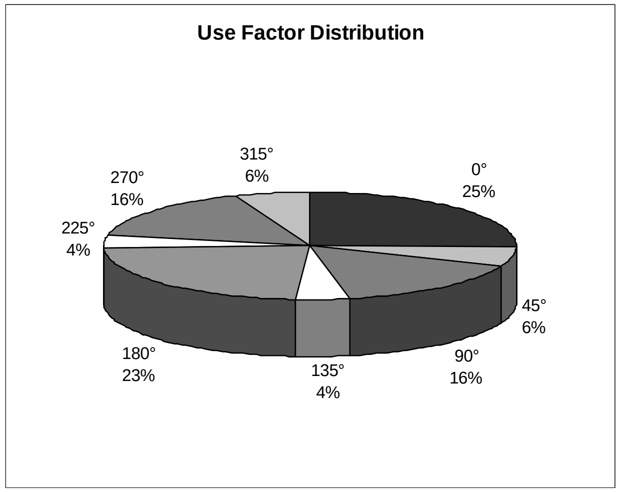


Fig. 4 Use factor distribution at 45 degree intervals for atypical therapy unit.

The report discusses design and structural details of the therapy facility including size and provision for future needs, interlocks and warning systems. Information is given of the effectiveness and structural usefulness of shielding materials such as ordinary and heavy concrete, lead, steel, polyethylene, earth and wood. Steel reinforcement bars and tie rods in concrete construction are shown to have no negative effect on the shield integrity. Proper placement and shielding of ventilation ducts and water and electrical conduits is recommended.

Special consideration must be given in certain instances for possible effects of skyshine. **Figure 5** shows the geometry and the parameters (height of the barrier, $d_1$, and solid angle, $\Omega$) that are considered in the model for estimating the dose from skyshine at some distance, $d_2$, outside the barrier. Groundshine radiation (radiation scattering under the barrier) may be a problem when thin laminated barriers are used. Side-scattered photon radiation is radiation scattered from the shield wall to locations outside the barrier.

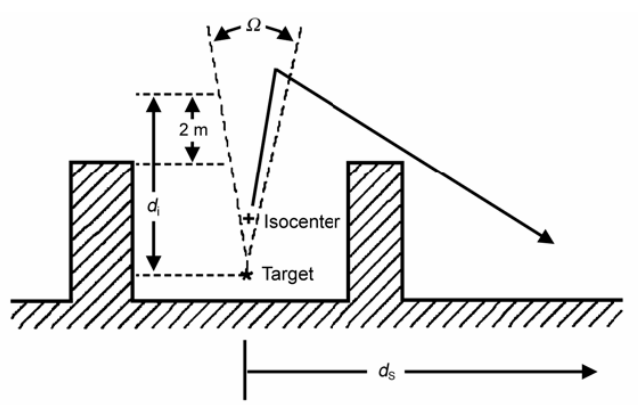


**Fig. 5 Simplified schematic showing the accelerator Isocenter, target location and geometry for photon skyshine evaluation.**

This could be a problem if occupied areas are nearby.

For units operating above 10 MV, neutron activation can produce Al-28, Mn-56, Na-24 and Sb-122 in various machine components and equipment or structures. For this reason and because of the increased dose to patients from neutrons, therapy beam energy should be kept below 10 MeV if possible. Ozone production is generally not a problem.

New technologies such as tomotherapy and robotic arm units may require greater barrier thicknesses for primary and leakage radiation and special consideration of workloads and beam orientation.
Detailed examples of barrier thickness calculations are given for a conventional treatment unit with an entry maze and with modifications for intensity modulated radiation therapy (IMRT), and for a robotic arm stereotactic radiosurgery room.

## CONCLUSIONS

These two reports follow the same basic methodology given in the previous NCRP reports, Nos. 49 and 51 for calculating barrier thickness. They bring this methodology up to date with new information, recent data and modeling for new technologies. Report No. 147 introduces the concept of Workload distributions to reduce the over-conservatism of the past. Together they provide a comprehensive facility and shielding design reference for medical x-ray imaging and radiation therapy facilities. They can be ordered from http://www.ncrponline.org/.

## REFERENCES

(1) NCRP, Structural Shielding Design for Medical X-ray Imaging Facilities, Report No. 147, 2004 (Revised March 2005), NCRP Bethesda, MD.
(2) NCRP, Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-ray Radiotherapy Facilities, Report No. 151, 2005, NCRP Bethesda, MD.