Guideline for Design and Validation of Shielding of Diagnostic X-ray Facility

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Department of Health

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Contents

Design and Validation of Shielding of Diagnostic X-ray Facility

Radiation shielding specifications and certification1 is carried out by accredited persons. Once certification has been granted an application to register the room(s) may be made by the person seeking to register the place.

The requirements in this document are those that must be used by accredited persons when calculating the structural shielding specifications for rooms where general radiographic, fluoroscopic and computed tomography X-ray units are used. The document also contains the requirements for validating and certifying rooms where these X-ray units are used.

This document draws on internationally recognised methodologies based on the work of the National Council for Radiation Protection and Measurements (NCRP 145) and the work of the British Institute of Radiology (BIR), Radiation Shielding for Diagnostic Radiology, 2012 (BIR 2012).

Requirement 1 - Method

The radiation shielding design report must state whether it has been designed following the methods and assumptions of NCRP 147 or BIR 2012. Using a mixture of these methods is not permitted.

Requirement 2 - X-ray Attenuation/Transmission

Attenuation of broad beam radiation through materials used for shielding must be specified using the empirical model of Archer BR, Thornby JI, Bushong SC (1983) Diagnostic X-ray shielding design based on an empirical model of photon attenuation, Health Phys, 44, 507-17.

Three phase and constant potential X-ray transmission through a variety of materials may be found at:

- Archer BR, Fewell TR, Conway BJ, Quinn PW (1994) Attenuation properties of diagnostic X-ray shielding materials, Med Phys, 21, 1499-507.
- Christensen R, and Sayeg JA (1979) Attenuation characteristics of gypsum wallboard, Health Phys, 36,595-600.
- Simpkin DJ (1989) Shielding requirements for constant potential diagnostic X-ray beams determined by a Monte-Carlo calculation, Health Phys, 56, 151-64.
- Simpkin DJ (1995) Transmission data for shielding diagnostic X-ray facilities, Health Phys 68, 704-9.
- Rossi RP, Ritenour R, Christodoulou E (1991) Broad beam transmission properties of some common shielding materials used in diagnostic radiology, Health Phys, 61, 601-8.
- Table A.1 NCRP 147

[1] The place has been issued a certificate of compliance issued by a person accredited under the *Radiation Protection Act 2005*

- Simpkin DJ and Dixon RL (1998) Secondary shielding barriers for diagnostic X-ray facilities: scatter and leakage revisited, Health Phys, 74, 350-65. This work made the simplifying assumption that scattered radiation has the same attenuation as primary radiation. This work shows negligible differences in transmission for energies below 100 kVp where the contribution from leakage is negligible. For calculations above 100 kVp, NCRP 147, BIR Table 4.3
- Computed Tomography secondary transmission curves NCRP 147, Table 4.4 BIR

Software used to determine shielding thicknesses must also make use of these models and attenuation data.

Requirement 3 - Accepted Lead Equivalence of Certain Materials

- Attenuation due to components of the radiographic system BIR 2.1.3, Table 2.2 and Table 2.3
- Standard Building Materials BIR 3.1 and Table 3.1.
- Table 3.3 Barium plaster
- Table 3.4 Lead glass
- Table 3.6 Lead glass and Lead acrylic

Requirement 4 - Dosimetric Quantities

The dosimetric quantity used in shielding design[2] is Kerma in air (also called air Kerma)[3] measured in gray (Gy) (BIR 1.2[4]).

Requirement 5 - X-Ray Workload and Kerma

The air kerma used to assess a barrier that may require shielding, can be calculated by applying the workload estimate for the X-ray unit to a normalised scatter (say at 1 m). Ideally, the workload estimate will be based on the actual number of procedures and the radiographic technique for those

[2] It should be recognized that radiation protection measurements are often performed in terms of International Commission on Radiation Units and Measurements operational quantities (ICRU). For example, individual doses, as recorded on a personal dose monitor, are assessed in terms of the operational quantity personal dose equivalent Hp(d) (d=0.07 mm or 10 mm). Radiation protection instruments are often calibrated in terms of another operational quantity, the ambient dose equivalent H*(d) (where d = 0.07mm or 10mm, with 10mm being used for strongly penetrating radiation). The relationship between derived quantities and air-kerma is complex, depending on the radiation spectrum and in the case of effective dose, distribution of photon fluence and posture of the exposed individual. Nevertheless, in the energy range used for diagnostic radiology air kerma generally represents an overestimate of the effective dose.

[3] According to the International Commission on Radiation Units and Measurements (ICRU), the relationship between effective dose and incident air-kerma is complex and depends on the attenuation of X-rays in the body. Therefore, it is not practical to use this quantity for shielding design purposes. This correlation is adopted in practical situations by using conversion coefficients calculated using validated mathematical models by the ICRU. The ambient dose equivalent, H*(10), is a quantity adopted by the IAEA for monitoring external exposure.

[4] The assumption of equivalence between air kerma and effective dose will result in conservative shielding models. It should be noted that because Hp(10) and H*(10) overestimate the effective dose by more than kerma does, caution should be taken if instruments calibrated in these quantities are used to determine, for example, levels of scattered radiation around a room as part of a shielding assessment exercise.

procedures. The X-ray workload for a procedure is the time current integral for an x-ray tube over a specified period and is expressed in milliamp minutes.

A measure of scattered Kerma can also be obtained by applying a scatter factor, S, to the DLP for CT or the KAP for fluoroscopy (BIR 2012 1.6). Annual, monthly or weekly values of DLP or KAP capture the workload of the X-ray unit and therefore the annual, monthly or weekly scattered Kerma.

NCRP 147, 5.6 'Computed Tomography' is a recognised method for obtaining air-kerma from DLP records. The use of isodose maps is also acceptable and it should be noted these are normalised air kerma per mAs at a distance which also captures the shielding effect of the gantry ('hourglass' curves). Use of isodose maps also means care needs to be exercised when interpreting mAmin data (NCRP 5.6.3)

Tertiary scatter for fluoroscopy and CT can also be derived in a similar manner (BIR 2012 2.4)

Requirement 6 - Occupancy

Occupancy adjusted air Kerma is used to calculate the required attenuation to meet the shielding design goal. The occupancy assigned is based on the fraction of time spent in a location by the person who is there the longest (BIR 1.5). When determining the air Kerma for a shielded barrier the distance to the occupied area of interest is taken to be from the source to the nearest likely approach of the sensitive organs of a person to the barrier. For a wall this is not less than 0.3 m. For a source located above potentially occupied spaces the sensitive organs of the person below is taken to be not more than 1.7 m above the lower floor, while for ceiling transmission the distance of at least 0.5 m above the floor of the room above is used. (NCRP 147 4.1.2).

In the absence of actual occupancy data for a particular situation, the following occupancy weighting factors may be used:

Table 1.1 – Occupancy Factors (BIR 2012)

Occupancy	Area type	Occupancy Factor
Full	Control rooms Reception areas, Nurses stations Offices, shops, living quarters, children's indoor play areas, occupied space in nearby buildings	1 (100%)
Partial	Staff rooms. Adjacent Wards, Clinic rooms, Reporting areas	1/5-1/2 (20% – 50%)
Occasional	Corridors, Storerooms, Stairways Changing rooms, Unattended car parks, Unattended waiting rooms Toilets, bathrooms	1/40-1/8 (5%-12.5%)

Table 1.2 - Occupancy Factor (NCRP 147)

Area Type	Occupancy Factor
Administrative or clerical offices; laboratories, pharmacies and other work areas fully occupied by an individual; receptionist areas, attended waiting rooms, children's indoor play areas, adjacent x-ray rooms. Film reading areas, nurse's stations, x-ray control rooms	1 (100%)
Rooms used for patient examinations and treatments	1/2 (50%)
Corridors, patient rooms, employee lounges, staff rest rooms	1/5 (20%)
Corridor doors	1/8 (12.5%)
Public toilets, unattended vending areas, storage rooms, outdoor areas with seating, unattended waiting rooms, patient holding	1/20 (5%)
Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), attics, stairways, unattended elevators, janitor's closest	1/40 (2.5%)

Requirement 7 - Use Factor

The use factor (U) determines the amount of time a barrier is exposed to the primary X-ray beam during radiographic procedures (i.e. when it is acting as the 'primary barrier'). All barriers are subject to leakage and scattered radiation. However, the primary X-ray beam may be oriented to obtain different radiographic projections thereby creating the need for 'primary barrier' shielding to be considered in numerous places.

The following factors may be used for the Use factor 'U'. U=0 for modalities where the primary beam is stopped by the imager receptor such as mammography and image intensified fluoroscopy

Use Factors from the AAPM TG 9 Survey (Simpkin 1996)

Of the total workload in radiographic room

- 22% at chest bucky wall
- 7% at cross-table lateral wall
- 2% at another, unspecified wall
- remainder (~70%) at floor

Of the workload not directed at the chest bucky

- 89% at floor
- 9% at cross-table lateral wall
- few % at another, unspecified wall

Requirement 8 - Shielding Design Goal

If using BIR 2012 methodology, then

- 0.3 mGy/year in situations where a member of the public may be exposed

- 6 mGy/year for occupational exposure

If using NCRP 147 methodology, then

- 0.25 mGy/year in situations where a member of the public may be exposed (NCRP 116 multiple sources)
- 5 mGy/year for occupational exposure

Requirement 9 - Calculations in Support of the Shielding Design

It is commonplace for shielding designs to be calculated with the aid of software (custom spreadsheets and freely available programs such as XRAYBARR (Simpkin)) which makes use of the methods described in Requirements 2 to 8 above. Any software being used for these purposes, especially custom spreadsheets, must be subject to regular quality assurance. This may best be achieved by benchmarking the software against worked examples in BIR 2012 or NCRP 147. Records of these checks must be kept and be available for inspection by regulators who authorise x-ray rooms or register X-ray equipment on the basis of their shielding designs.

Requirement 10 - Practical Assessment of Shielding

Visual inspection of shielding and building certificates and orders should be carried out by the shielding designer as the shielding is installed. Lead glass commonly has a glazier's certificate and must be indelibly labelled with a lead equivalence at a specified kVp. Visual inspection also provides an opportunity to perform physical measurements of lead plaster and sometimes concrete thicknesses.

Voids and gaps in the shielding may be readily identified during construction. Photographic records form a useful resource. (BIR 2012 5.2, NCRP 147 6.2, 6.3.1).

Checks may also be carried out using radioactive sources and X-ray units (BIR 2012 5.3, NCRP 6.2). The use of radioactive materials can require careful interpretation of the results as the spectrum of radiation from the materials is often different to that of X-rays. The most suitable radioactive material for checking shielding is Am-241 whose 60 keV gamma peak represents the upper part of photon energy range of typical diagnostic X-ray beam. Tc-99m may be used as an alternative to Am-241 for this purpose, but there are limitations which need to be accounted for (BIR 2012 5.3). BIR 2012 5.3.2 includes a useful discussion regarding the attenuation of barriers made from various materials.

Measurements may also be made using diagnostic X-ray equipment. This has the advantage of testing the barrier against the radiation for which it was designed (BIR 2012 5.6, NCRP 147 6.3.2, 6.3.3, 6.3.3.1, 6.3.3.2, 6.3.3.3,6.3.3.4, 6.3.3.5 6.3.4)).

Any barrier testing must include a calculation of the lead equivalence of the barrier and include testing of potential weak points such as penetrations, windows and doors (including the frames and hardware), and joins in materials.

If a visual assessment and examination of building documentation indicates that the shielding has been installed as per the design requirements, and that penetrations have been appropriately addressed to ensure continuity of shielding, then further testing is not necessary.

Requirement 11 - Advice Regarding Doors, Windows and Penetrations

As part of the shielding design advice must be provided, on how to ensure continuity of shielding at windows and doors (including the frames and hardware), and joins in the shielding materials, and on how to address penetrations to the shielding materials, such as for light switches, power points, electrical cabling and plumbing.

This advice must include consideration of the distance between the original layer of material and the additional material installed, to ensure the shielding of glancing angle X-rays. The shielding requirement for a door or window (including the frame) must be the same as the requirement for the wall it forms part of. The occupancy factor assigned to all parts of a barrier which forms the operator shield must be 1 (i.e. 100%).

The shielding height requirements depend on the nature of the equipment and the following height requirements[5] must be incorporated within the shielding design:

- no less than 2.1m for general radiography, fluoroscopy, mammography, BMD/DEXA, OPG, intraoral, dental CBCT and nuclear medicine; and
- no less than 2.7m or to the upper slab, whichever is the lower for CT, including SPECT/CT, PET/CT and all other non-dental CBCT.

[5] For high dose areas including CT and interventional radiology, shielding design depends on a number of site-specific factors so shielding designers are asked to refer to authoritative texts which deal with these cases such as [1] and to specify height requirements greater than those indicated above, where applicable.
[1] Sutton, D.G., Martin, C.J., Williams, J.R., Peet, D.J., Radiation Shielding for Diagnostic Radiology, 2nd Edition, British Institute of Radiology, London (2012).

Annexe A - Form of the Shielding Report and Certificate of Compliance

The accredited person must produce a shielding report containing:

- A scaled floor plan of the place to which the shielding report applies.
  - The floor plan must include all occupied locations around the X-ray unit(s).
  - The floor plan must assign the numerical occupancies from NCRP or BIR to the locations around the X-ray units (including areas outside the place) and dimensions from the source of exposure to these locations.
- X-ray workload and technique for each X-ray unit in the place
- Unambiguous markings or legend on the plan that identify the thickness and type of any additional structural shielding required, or of existing structural materials that will provide sufficient shielding (e.g. existing block work or plaster)
- Any manufacturer's radiation scatter diagrams that were used to estimate exposure

When the accredited person is satisfied the place complies with the specification in the shielding report a 'Certificate of Compliance' for the place may be issued.

A certificate of compliance for a radiation place must contain at least the following information:

- Address and room number(s) sufficient to uniquely identify the place.
- The date that compliance was finally determined.
- The name and signature of the holder of the certificate of accreditation under which the certificate of compliance is being issued.
- The title of the Code of Practice the radiation place was assessed against.
- A statement to the effect that the certificate of compliance is being issued in accordance with the requirements of the Tasmanian Radiation Protection Act 2005.
- A certificate of compliance identification number, which must be of the form:
  The final date, as year (YYYY), month (MM) and day (DD), on which the assessment of the radiation place demonstrated that the place was in compliance with the relevant Code of Practice and any other prescribed specifications followed by a four digit Radiation Place Identification Number (RPIN provided by the regulator).
  For example: 2010 07 31 0251 means that the place with identification number 0251 was shown to comply with the relevant Code of Practice and any other prescribed specifications on 31 July 2010.