Shielding in diagnostic radiology

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X-ray rooms should be designed to provide flexible and efficient working areas for different types of imaging procedure. As far as radiation protection is concerned, they must be capable of containing the radiation produced as a result of the examination to within limits determined by the Ionising Radiations Regulations 1999 (IRR99).

The radiation itself arises from three main sources – the primary beam, leakage from the x-ray tube and scatter from the patient. Leakage and scatter are referred to as secondary radiation. Room shielding needs to be designed so that protection is provided against both primary and secondary radiations. The doses from each that are incident on the barrier to be shielded are closely linked to the amount of radiation to which patients are exposed.

The design of protection is not a particularly precise science but attempts have been made to formalise it. The approach outlined here follows the methodology recommended in the recent BIR publication, which contains a compendium of information. As with any process, it is important that it is inclusive and it is imperative that any shielding design involves input from everyone involved, who in this case are most likely to be x-ray department staff, physicists and architects. It is also important that future needs are borne in mind when considering the design.

Dose and design limits

The dose limits defined in IRR99 are expressed in terms of effective dose while most x-ray output and transmission data are measured using air kerma. This means that it is not practical to use effective dose, or the operational quantities used to describe it, when calculating shielding requirements. To get round this, an approximate equivalence is made between effective dose (mSv) and air kerma (mGy). This is a conservative assumption since air kerma represents an over-estimate of effective dose at diagnostic x-ray energies.

In practice, the two distinct groups of people that must be considered when designing shielding for an x-ray room are members of the public (including employees not directly concerned with the work of the room) and employees who will be using the particular room in question. The design methodology used must satisfy the dose limits for both groups. Members of the first group are subject to the annual dose limit for members of the public (1mSv). It is completely possible that a member of the public will receive a radiation dose from more than one source. For example, a person may work in an office next to an x-ray room and also live near an incinerator where radioactive waste is burned. So, to ensure that someone does not receive the maximum allowable amount of radiation from a single source, designs must limit the potential exposure of members of the public to a fraction of the dose limit. This is termed a dose constraint and it is usual to apply a constraint of 0.3 when designing protection for x-ray rooms. The design limit used is therefore 0.3mSv per annum to a member of the public. This application of the dose constraint must be made using realistic assumptions regarding the occupancy of surrounding areas. The occupancy factor for an area is not the time during which it is occupied by a group of people (such as patients in a waiting room) but instead represents the fraction of time spent by the single person who is there the longest. Consequently, the occupancy factor is best defined as being the fraction of an eight-hour day, 2,000 hour year or other relevant period for which a particular area may be occupied by a single individual. Occupancy factors should, wherever possible, be based on realistic data obtained from the installation site, so it is important to consider the fact that the use to which an adjacent space is put may change over the lifetime of the x-ray installation. Typical values of occupancy factor would be 100% for an adjacent office, 20-50% for adjacent staff rooms or reporting areas and 5-10% for corridors and WCs. It is really important to consider surrounding areas and the use to which they may conceivably be put in the future, when considering a shielding design.

Although the dose limit for employees is considerably higher than that for members of the public, experience has shown that a dose constraint of 0.3mSv is clearly achievable for them as well and should be applied as a design goal. An obvious example of this is the practice of placing a suitably designed operator’s console behind a protective barrier in a plain film room.

Workload and calculation

In order to evaluate how much protection needs to be provided by a barrier, it is necessary to determine the annual kerma that will be incident on it. This can be derived from the work carried out in the x-ray room, expressed in terms of the dose to patients and known as the workload. The most appropriate source of information for estimating workload is local dose audit. If this information is not available, then published data or calculation can be used.

Primary radiation will only be incident on the barrier in the case of plain radiography, but scattered radiation will need to be taken into account no matter what the modality. In the case of primary radiation, the kerma incident on a barrier for any projection can be estimated using the patient entrance surface air kerma (ESAK) corrected by the inverse square law for the distance from the patient to the barrier, and by making allowance for backscatter from the patient. The annual kerma incident on the barrier can then be determined by addition. If appropriate, allowance can be made for attenuation by intervening structures, such as a chest Bucky or a table. ESAK can be directly measured or obtained by calculation if the output factors are known. Alternatively, a figure of 0.15mGy per projection can be used for chest radiography and a simple factor of 2.6mGy per Gycm² can be applied to relate ESAK and KAP in the case of table radiography.

The scatter kerma (Kₘ) is closely related to the KAP and follows the S shape shown (Figure 1). The least scatter occurs in the forward direction and the most is directed back towards the tube. A simple equation can be used to derive the maximum scatter at one metre from the patient, which...
varies from 4.4 to 5.6 μGy per Gycm² in the primary beam over the range 60 to 100kV. When x-ray beams filtered by additional copper are used, as is often the case in a cardiac catheterisation laboratory, the scatter kerma at one metre can be taken as being 8 μGy per Gycm³.

The scatter kerma from CT installations can be calculated using a very similar approach, except in this case the scatter kerma resulting from a CT examination can be determined from the DLP for that examination using an equation of the form \( K_S = \text{DLP} \times S_{CT} \). The values of \( S_{CT} \) are different for head and body examinations and also vary with direction because of the well-known hour glass distribution of scattered radiation around a CT scanner (Figure 2), which depends on the design of the scanner gantry, the exposure parameters used and beam collimation and filtration. However, conservative designs can be produced using a value for \( S_{CT} \) of 0.14 μGy per mGycm for radiation scattered from head examinations and 0.36 μGy per mGycm for radiation scattered from body examinations.

Once the annual kerma incident on the barrier is known then it is possible to determine the amount of shielding that will be required to reduce that kerma to the dose constraint. The required transmission is defined as being the quotient of the dose constraint divided by the annual kerma incident on the barrier. A very useful equation, known as the Archer equation, can then be used to determine the thickness of any given material required to provide the required amount of transmission. Three kV dependent parameters, \( \alpha \), \( \beta \) and \( \gamma \), are required as input to the equation and can be obtained from published tables for a range of materials used for protection purposes. By way of example, suppose that the annual kerma from a CT scanner incident on a barrier was 200 mGy and the area to be protected was a staff room, which would be unlikely to be occupied by any one person for more than 50% (=0.5) of the time. As part of the discussion process prior to the protection being designed, it has been identified that majority of the CT examinations were obtained at 120kV. The required transmission would be given by \( T = 0.3 / (0.5 \times 200) = 0.003 \). The Archer equation can be used to show that this amount of transmission will be provided by 1.6 mm lead or 140 mm of concrete with density 2350 kg/m³.

### Some practical matters

Lead sheet is readily available in a standard range of thicknesses and the most cost-effective design will specify one of these, and will probably use the same specification on all walls, to avoid construction errors and to provide future proofing. If lead is not used, concrete is a good substitute at diagnostic energies (gypsum wallboard will often do for dental radiology) but care needs to be taken over the density used in construction. Lead doors and surrounds are difficult to construct and experience suggests that purchases from a reputable and experienced supplier reduce problems later on. Finally, it is a very good idea to visit the room while the construction is in progress to make sure that what you think is happening actually is, and to avoid difficulties that are bound to occur if post construction measurements reveal problem areas.

### A glossary of some terms

- **Air Kerma:** The dose in gray (Gy) to air, as measured by an ionisation chamber. In diagnostic radiology it is the same as absorbed dose. Kerma stands for ‘kinetic energy released in matter’.
- **DLP:** Dose length product. This quantity is the product of CTDIvol and scan length. It is displayed on all modern CT scanners in terms of mGycm.
- **ESAK:** Entrance surface air kerma. Also known as entrance surface dose, this is the dose in Gy to a patient in a primary x-ray beam and can be measured using for example thermoluminescent dosimeters, calculated from measured output values or derived from kerma area product data.
- **KAP:** Kerma area product. Also known as dose area product (Gycm²), this is the product of the air kerma and field size. It is, to all intents and purposes, invariant with distance from the x-ray set and is displayed on all modern radiographic and fluoroscopic equipment.

### Reference