

RADIATION PROTECTION IN INTERVENTIONAL RADIOLOGY

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Interventional radiology procedures can require substantial amounts of ionizing radiation and therefore necessitate particularly close attention to radiation protection. In this chapter, radiation units, regulations, and the fundamental principles of radiation protection are reviewed. Then the procedures and devices designed to reduce patient and staff exposure in interventional radiology are examined.

RADIATION UNITS

The fundamental interactions of x-rays with matter produce ion pairs via photoelectric and Compton interactions.¹ The *Roentgen* (SI unit: coulomb (C) per kilogram) is the unit used to measure the number of ion pairs produced by x- or γ radiation in a standard volume of air. The process of ion pair production is formally termed *radiation exposure* and is fundamental in radiation protection.

The number of ion pairs produced in air does not directly measure the amount of energy deposited in another medium because of the differences in x-ray absorption by different materials.¹ The *rad* is used as a measure of the radiation *absorbed dose* (energy deposited per unit mass). A rad is equal to 100 ergs/g (SI unit: joule per kilogram or Gray (Gy)). This unit is of fundamental importance in patient dosimetry.

Ionizing radiations other than x- and γ rays, such as α particles or neutrons, may induce a greater biologic effect for a given absorbed dose. To quantitate this observation, the *rem* (SI unit: Sievert (Sv)) is used to measure the *dose equivalent*. The rem is equal to the number of rads multiplied by a quality factor ranging from 1 to 20 that expresses the degree of biologic insult for equal amounts of different types of ionizing radiation. The quality factor for x- and γ radiation is equal to 1. This unit is most often utilized in health physics and personnel exposure measures. These radiation units are summarized in Table 1.1.

RADIATION PROTECTION FUNDAMENTALS

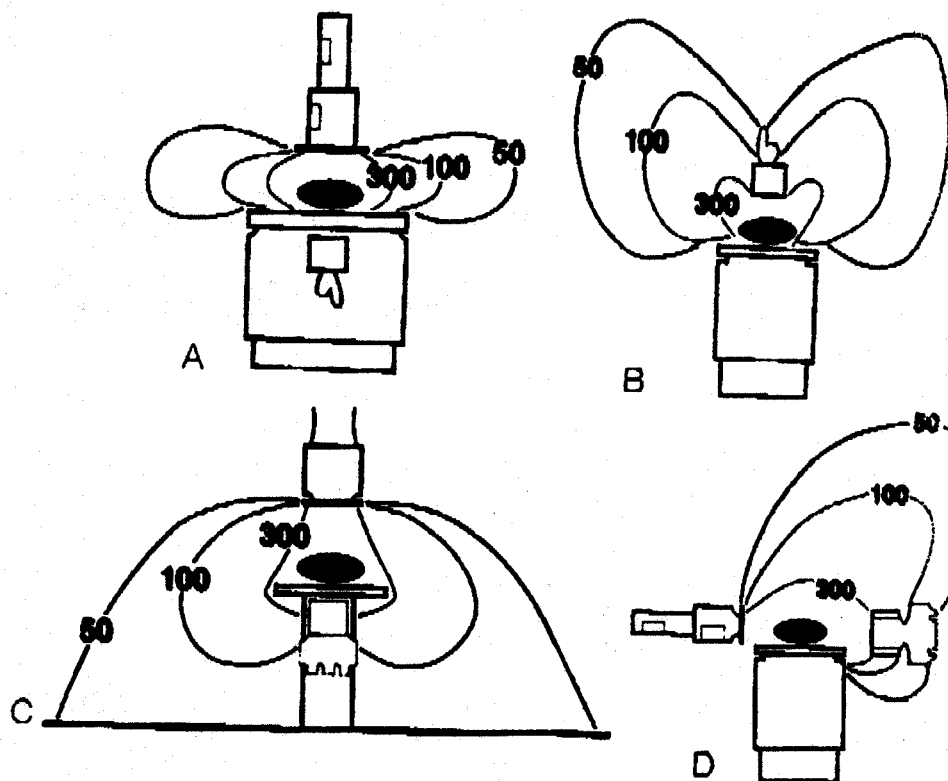
In order to decrease the absorbed dose to the patient and the exposure of the staff, the radiation protection principles of time, distance, and shielding must be considered. Radiation exposure is directly related to exposure time, so by halving the exposure time, one halves radiation dose. Because an x-ray beam diverges as it passes through space, radiation intensity decreases as the inverse square of the distance from the radiation source:

$$\frac{I_2}{I_1} = \frac{d_1^2}{d_2^2}$$

Hence, if the distance from a radiation source is doubled, the radiation intensity decreases to one-fourth its original value (Fig. 1.1). Although this relation holds strictly only for a point source, the distance principle is useful in reducing clinical radiation exposure when the patient is the principal source. The attenuation of an x-ray beam (loss of intensity as it passes through matter) is exponential ($I = I_0 e^{-ux}$, where I and I_0 are the initial and transmitted radiation, respectively, u is the attenuation coefficient of the material (which depends on the atomic number and density and on the energy of the photons), and x is the thickness of the attenuating material). Therefore, small amounts of attenuating (*shielding*) material can greatly reduce the intensity of an x-ray beam. For example, a 99% reduction of a diagnostic x-ray beam is obtained by using a 0.5mm Pb-equivalent material. Examples of exponential attenuation for diagnostic radiology x-ray beams are shown in Figure 1.2.

Because fluoroscopy is utilized extensively during some interventional radiology procedures, the continual observation of these fundamental principles is of far greater importance than in most areas of diagnostic radiology. ★

Figure 1.3. Scatter radiation from several equipment configurations. Isoexposure lines are given in millirads/hr. A. Conventional fluoroscopy. B. Overhead tube. C. Posteroanterior fluoroscopy with C- or U-arm. (Courtesy of General Electric Medical Systems Division.)



to see the beam entrance area directly. In addition to the amount of time spent in a particular area during a procedure, overall distance from the patient is also important and indeed may be a primary consideration for some staff members. For example, anthropomorphic-phantom measurements of eye exposures for individuals 5 feet 10 inches and 6 feet 4 inches tall demonstrated an exposure increase of approximately 70–115% for the shorter individual.³ Different radiation protection considerations therefore may be necessary depending on staff members' heights. Because it is not always possible to change one's position relative to the beam, many devices have been suggested to reduce staff exposure during interventional radiology procedures.^{12–17} Unfortunately, effective devices are often somewhat awkward given the usual time and space demands of interventional radiology.

In addition to time, distance, and shielding, another important radiation protection parameter is x-ray beam size. The amount of scattered radiation exposure is directly related to beam size. In addition, the patient dose and image quality are affected by changes in collimation. Hence, by limiting the beam size to the smallest necessary area, the fluoroscopist can decrease both personnel and patient exposures while improving image quality.

The recent concept of surface shielding consists of shielding the operator's line of sight from the patient's surface rather than the operator's level.^{12,19} The shielding may be fabricated in strips or solid pieces from lead aprons and therefore may be sterilized for reuse. Typical radiation exposure reductions with a 0.77mm surface shield can range from 33–75% (Fig. 1.4). The use of such devices is

important to minimize staff radiation exposures and comply with regulations.

To provide perspective on the radiation exposure encountered in interventional radiology, consider the following example:

If Radiation exposure = 300 mR/hr,
 fluoroscopy time = 0.5 hr/exam, and
 maximum permissible exposure = 1.25
 R/quarter,
 then Allowable procedures = 8 exams/quarter!

The importance of attention to radiation protection during these procedures is apparent (Table 1.4).

In summary, to minimize personnel exposure during fluoroscopic interventional radiology, the lowest acceptable exposure rate and smallest acceptable field size should be used with the most efficacious equipment configuration.^{20–22} Additionally, although the inverse-square law is not strictly maintained in fluoroscopy,²⁰ distance from the patient should be maximized, and, when possible, shielding material should be placed between the patient and personnel.

RADIATION PROTECTION IN CINEFLUOROGRAPHY

Because cinefluorography (cine) is an extension of fluoroscopy, all of the previous radiation protection considerations apply; however, radiation exposure is significantly

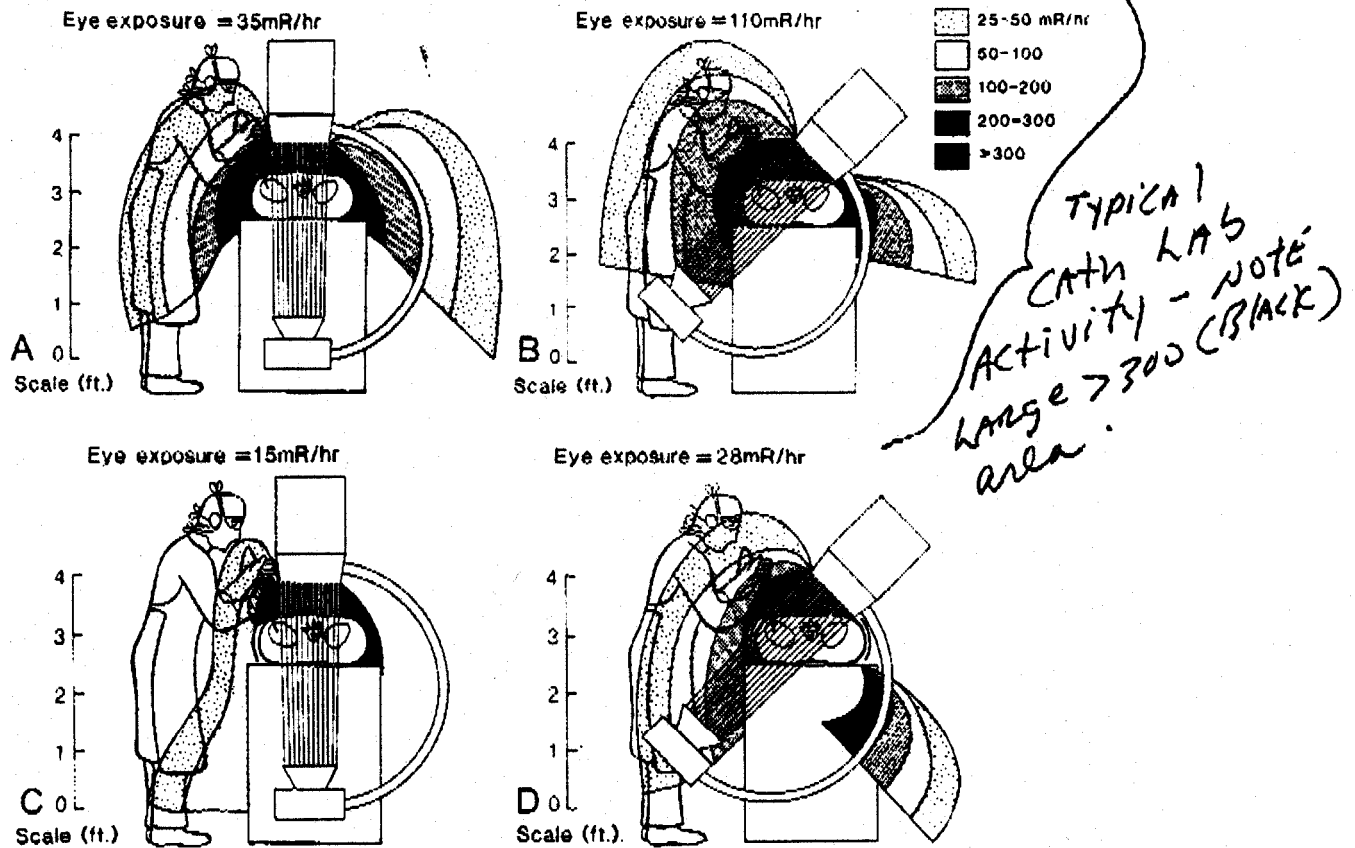


Figure 1.4. Scatter radiation reduction with surface shielding (2.8 R/min patient skin entrance exposure). A. Vertical fluoroscopy without shielding. B. Oblique (45°) fluoroscopy without shielding. C. Vertical fluoroscopy with a 25 x 15cm (0.75mm lead equivalent) surface shield. D. Oblique

(45°) fluoroscopy with surface shielding in place. (Reprinted from Young AT, Morin RL, Hunter DW, et al: Surface Shield: device to reduce personnel radiation exposure. *Radiology* 1986;159:801-803 with permission of the Radiological Society of North America, Inc.)

higher for the patient as well as the staff. Typical patient skin entrance exposures can range from 20-90 R/min,²³⁻²⁵ depending on the system and image acquisition parameters—substantially higher than the typical 2-3 R/min^{24,25} skin entrance exposures in fluoroscopy. The scattered radiation levels shown in Figure 1.4 were obtained with a skin entrance exposure of 2.8 R/min; to depict the cine scattered radiation exposure, the values in the figure should be multiplied by a factor of 7 to 32! Eye exposures for cine without shielding would range from 245-3520

mR/hr. The use of surface shielding would decrease these eye exposures to 105-896 mR/hr. Additionally, measurements indicate that eye exposure reductions of 84% are possible by changing the operator's position from table side to 30cm from the table.²⁰ Such reductions are system-dependent and should be verified for a particular radiology suite.

From these observations, it is apparent that distance and shielding radiation protection techniques should receive increased attention when cine is used during interventional radiology procedures.

Table 1.4. Maximum Number of Fluoroscopic Procedures in a 3-Month Period without Exceeding Eye Exposure of 1.25 R/Quarter

Fluoroscopic Time per Procedure (hr)	Radiation Exposure at Eye Level (mR/hr)					
	10	25	50	100	200	300
0.10	1250	500	250	125	62	41
0.25	500	200	100	50	25	16
0.50	250	100	50	25	12	8
0.75	166	67	33	16	8	5
1.00	125	50	25	12	6	4
1.50	83	33	16	8	4	2
2.00	62	25	12	6	3	2

RADIATION PROTECTION IN COMPUTED TOMOGRAPHY

The scatter radiation distribution surrounding a computed tomography (CT) scanner is, of course, quite different from the exposure levels found in fluoroscopy, both because the beam area is much smaller during slice acquisition and because the x-ray tube gantry surrounds the patient, thereby providing shielding. Typical isodose lines for a CT scanner are shown in Figure 1.5.^{10,27} Head and neck exposures could range from approximately 300-