Handling Radionuclides and Radiation Safety

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Transport, preparation, administration, and imaging of radiopharmaceuticals inevitably results in low, but non-zero, radiation doses to personnel as well as patients and are thus subject to federal, state and local regulations [1–5]. Table 3.1 summarizes the relevant regulatory agencies and the scope of their regulatory oversight [6]. These agencies specify records that must be kept and procedures that must be followed to ensure the safe handling of these agents. Such regulatory oversight is not intended to extend to the actual practice of medicine; for example, there is no regulation limiting the administered activity of a radiopharmaceutical prescribed for a patient, as prescription of this activity is considered part of medical practice.

Agency (Abbreviation)	Scope of oversight	Comment
Nuclear Regulatory Commission (NRC)	Regulates civilian use of radioactive by-product materials	Regulations are found in Title 10 of the Code of Federal Regulations (10 CFR) [2]. The most important parts for medicine are Parts 19, 20, 30 and 35
Agreement States (*ie*, states to which the NRC has delegated its regulatory authority)[a]	Regulate the same radioisotopes as the NRC, as well as naturally occurring and accelerator-produced radioisotopes	Also regulate medical x-ray and other radiation-producing equipment, often through state health departments or equivalent agencies
Non-Agreement States[a]	Regulate naturally occurring and accelerator-produced radioisotopes, but regulation of radioactive by-product material is still performed by the NRC itself	Also regulate medical x-ray and other radiation-producing equipment, often through state health departments or equivalent agencies
Food and Drug Administration (FDA)	Regulates radiopharmaceutical development through the following mechanisms: Radioactive Drug Research Committee (RDRC) protocols, Investigational New Drugs (INDs), and New Drug Applications (NDAs)	Regulations are found in Title 21 of the Code of Federal Regulations (21CFR) [1]. Also regulates the performance and radiation safety requirements of medical x-ray and other radiation-producing equipment
Department of Transportation (DOT)	Regulates the transport of radioactive materials	Regulations are found in Title 49 of the Code of Federal Regulations (49 CFR) [3]
Environmental Protection Administration (EPA)	Regulates release of radioactive materials to the environment	Regulations are found in Title 40 of the Code of Federal Regulations (40 CFR) [4]

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The following national and international *advisory* agencies provide information on radiation risks which are often used by regulatory agencies in formulating radiation-protection regulations: the National Council on Radiation Protection and Measurement (NCRP), the Biological Effects of Ionizing Radiation (BEIR) Committee of the National Research Council/National Academy of Sciences, the International Atomic Energy Agency (IAEA), the International Commission on Radiological Protection (ICRP), and the United National Scientific Committee on Effects of Atomic Radiation (UNCEAR)
[a]Over 40 states are currently Agreement States

Table 3.1 Regulatory oversight of medical uses of isotopes in the United States [6]

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Table 3.2 summarizes the various dosimetric quantities and units relevant to nuclear cardiology [6], and Fig. 3.1 shows the regulatory dose limits for occupationally exposed individuals (such as nuclear cardiology personnel) and non–occupationally exposed individuals (such as members of the general public) [2, 5]. Importantly, as shown in Table 3.3, the average annual doses—*ie*, the total effective dose equivalents (TEDEs)—to nuclear medicine and nuclear cardiology personnel are an order of magnitude higher than the regulatory dose limit for non-occupationally exposed individuals [2, 7, 8]. The annual hand dose to radiopharmacists is a significant fraction of (but still lower than) the corresponding dose limit [2, 7, 8]. Overall, these data suggest that sound radiation safety practice is very effective in minimizing occupational doses in nuclear medicine and nuclear cardiology.

Quantity	Symbol	Definition	Conventional unit (abbreviation)	System International (SI) unit (abbreviation)	Units conversions
Exposure	X	Electric charge produced per unit mass of air by x-rays or gamma rays	roentgen (R)	Coulomb per kilogram (C/kg)	$1\ R = 2.58 \times 10^{-4}$ C/kg 1 C/kg $= 3.94 \times 10^{3}$ R
Absorbed dose	D	Energy deposited per unit mass	rad	Gray (Gy)	1 rad $= 1 \times 10^{2}$ erg/g 1 Gy = 1 J/kg 1×10^{2} rad = 1 Gy 1 cGy = 1 rad
Kerma	K	Kinetic energy released per unit mass	rad	Gray (Gy)	1 rad $= 1 \times 10^{2}$ erg/g 1 Gy = 1 J/kg 1×10^{2} rad = 1 Gy 1 cGy = 1 rad
Dose equivalent[a]	H	$w_R \cdot D$	rem	Sievert (Sv)	1×10^{2} rem = 1 Sv 1 cSv = 1 rem
Effective dose[b]/ Effective dose equivalent[c]	H_E	$\sum_{Tissue,T} w_T \cdot H_T$	rem	Sievert (Sv)	1×10^{2} rem = 1 Sv 1 cSv = 1 rem
Activity	A	Amount of radioactivity expressed as the nuclear transformation rate (disintegrations per second, dps)	Curie (Ci)	Becquerel (Bq)	$1\ Ci = 3.7 \times 10^{10}$ dps 1 Bq = 1 dps $1\ Ci = 3.7 \times 10^{10}$ Bq $1\ Bq = 2.7 \times 10^{-11}$ Ci

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[a]The radiation weighting factor, w_R, reflects differences among radiations (R) in their ionization density and therefore their biological effectiveness, with more densely ionizing radiations such as alpha particles having a greater probability of producing biological damage and/or producing more severe biological damage than less densely ionizing radiations such as x-rays and gamma rays. The currently assigned values of w_R are as follows: 1 for x-rays and gamma rays and for beta particles and other electrons, 2 for protons, ≥5 for neutrons (depending on their energy), and 20 for alpha particles [11]

[b]The tissue weighting factor, w_T, reflects differences among human tissues (T) in their sensitivity to stochastic radiation damage (*ie*, cancer induction and germ cell mutagenesis and resulting heritable genetic damage). The currently assigned values of w_T range from 0.01 for brain and other "radioresistant" tissues to 0.12 for lung and other "radiosensitive" tissues. Note that $\sum_{Tissue,T} w_T = 1$. In principle, the effective dose provides a single-value metric of overall stochastic risk for any given irradiation [11]

[c]The effective dose equivalent is a quantity similar in concept to the effective dose. It is an older quantity than the effective dose but is still found in regulations (*eg*, to express the maximum permissible dose for occupationally exposed individuals) issued by the Nuclear Regulatory Commission (NRC) [2]. In addition to subtle technical differences, the effective dose equivalent differs from the effective dose in that fewer tissues are included in the summation, and the tissue weighting factors have somewhat different values

Table 3.2 Quantities and units in radiation dosimetry

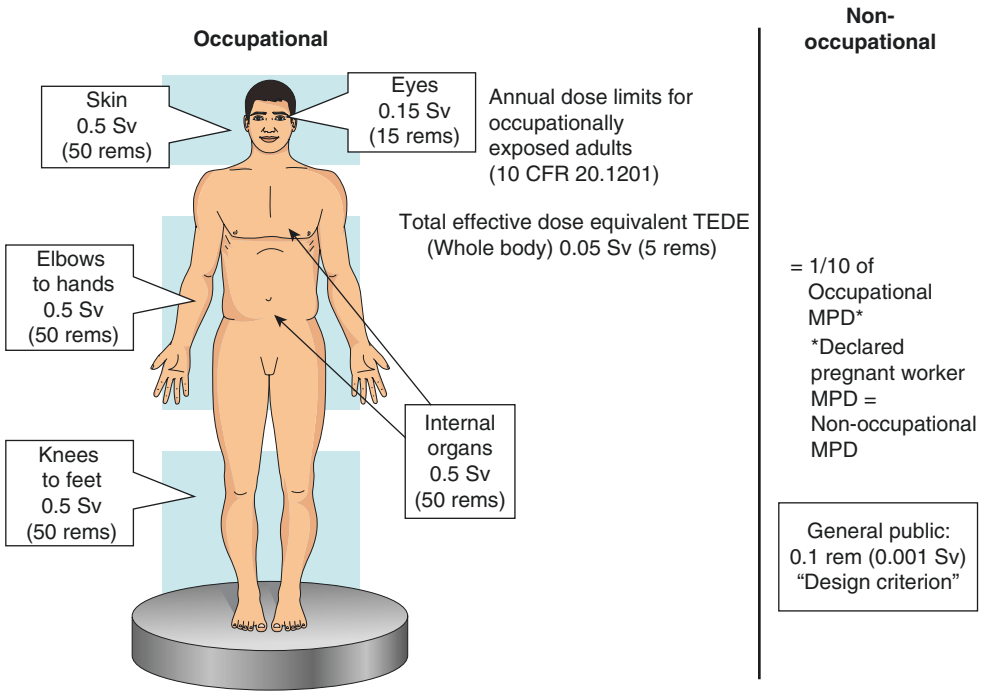


Fig. 3.1 Regulatory maximum permissible doses (MPDs) for individual occupational exposure and nonoccupational exposure, expressed as the annual limit for the effective dose equivalent. Note that the dose limits vary depending on the part of the body exposed, with the annual limit for the total (or whole-body) effective dose equivalent (TEDE) being 5 rem (0.05 Sv). The annual TEDE limit for a non-occupationally exposed individual (such as a clerk in a nuclear cardiology facility) is 0.5 rem (0.005 Sv), one tenth of that for an occupationally exposed individual. For a pregnant occupationally exposed individual who has "declared" her pregnancy (*ie*, disclosed her pregnancy to her employer), the TEDE limit is 0.5 rem (0.005 Sv) for the total duration of the pregnancy. In addition to the personnel dosimeters she would otherwise wear (typically at the collar level and possibly a ring dosimeter), a pregnant occupationally exposed individual should also wear a dosimeter in the abdominal-pelvic area to monitor the fetal radiation dose. Note that the annual TEDE for the general public is 0.1 rem (0.001 Sv); this limit actually serves as a design criterion for designing the shielding and configuration of a radiation facility to maintain the annual TEDE to individuals in adjoining public areas to less than 0.1 rem (0.001 Sv) [2])

References	Personnel	Total Effective Dose Equivalent (TEDE) (whole body),[a] *rem*	Hand dose equivalent,[b] *rem*
Bloe and Williams [7]	Nuclear medicine, General	0.18	0.99
	Nuclear medicine, PET	0.41	1.7
	Radiopharmacy	0.18	14
Owens and Hung [8]	Nuclear cardiology	0.14	0.072
	Nuclear medicine, General	0.072	0.060
	Radiopharmacy	0.29	21
	Injection	0.30	1.0

Adapted from Limacher et al. [6]; with permission from Elsevier
[a]Regulatory annual TEDE limit is 5 rem for occupationally exposed individuals [2]
[b]Regulatory hand dose-equivalent limit is 50 rem for occupationally exposed individuals [2]

Table 3.3 Average annual radiation doses to nuclear medicine and nuclear cardiology personnel

Nuclear cardiology personnel are exposed to radiation emitted by radioactive sources such as radionuclide generators, radiopharmaceutical vials and syringes, and, of course, radioactive patients. Potentially, internal exposure (or contamination) from radioactive materials that are inadvertently ingested, inhaled, or otherwise internalized may contribute to the radiation dose. Because nuclear cardiology does not utilize radioactive gases or aerosols or radiopharmaceuticals that are significantly volatile, routes of internal contamination are limited to ingestion or absorption through skin. Strict adherence to sound radiation safety practice (Table 3.4) should reduce internal exposures of personnel to insignificantly low levels, and bioassay of personnel (*eg*, whole-body surveys, counting of urine samples) is routinely not performed in nuclear cardiology.

Eating, drinking, smoking, and applying cosmetics are prohibited
Disposable waterproof gloves, a laboratory coat, and a personnel dosimeter should be worn at all times. Gloves should be changed regularly to minimize any potential spread of contamination, and a laboratory coat worn when handling radioactive materials should be stored in the area in which such materials are handled (*ie*, should not be worn outside that area)
All working surfaces should be covered with absorbent sheets having a water-impermeable plastic coating facing the benchtop
Radioactive materials should be kept in closed vials in suitably shielded containers. Syringes, vials, etc. containing radioactive materials should likewise be transported in suitably shielded containers
Shielded containers and vials containing radioactive materials should bear a label identifying the material (including the radioisotope), the activity, and the time and date of calibration of the activity
Dispensing and other manual handling of radioactive materials should be performed with suitable shielding between the user and the radioactivity
To the extent possible, dispensing and other manual handling of radioactive materials should be performed using forceps or tongs
Radioactively contaminated solid waste should be discarded in suitably shielded and labeled waste receptacles
To avoid accumulation of excessive volumes of radioactive waste, such waste should be segregated according to physical half-life for decay in storage—for example, waste with physical half-lives longer than 1 day, longer than 1 day but shorter than 1 week, and longer than 1 week but shorter than 1 month
Radioactive waste with a physical half-life longer than 1 month may be too long-lived to hold for decay in storage on-site and may therefore need to be disposed of commercially. (This is rarely, if ever, the case in nuclear cardiology, however.)
Radioactive waste can subsequently be discarded as nonradioactive waste once it is no longer *detectably* radioactive
Radioactively contaminated liquid waste should generally be discarded into the sewer system—that is, down a drain or into a toilet. The drain or toilet should then be rinsed thoroughly by running water into the drain (taking care to avoid splashing) and flushing the toiler twice
Personal items (books, clothing, etc.) should not be placed on laboratory work surfaces
When handling radioactive materials, interruptions and other distractions from the task at hand should be avoided
A suitable electronic (*ie*, real-time) radiation detector should be available and activated in the area where unsealed radioactive materials are handled
Recording of activities and other pertinent data should be performed in real time (not retroactively) and directly into the "official" laboratory record
Once the handling of radioactive materials has been completed, hands should be washed and hands, shoes, and clothing should be monitored for contamination in a low-background area

See Table 3.6 and the figures cited therein for the supplies and equipment required to implement these radiation safety measures

Table 3.4 Basic radiation safety measures for handling unsealed radioactive materials

Sound radiation safety practice is predicated on the common-sense measures of time, distance, and shielding:

- Minimize the time spent in close proximity to radioactive and other radiation sources.
- Maximize the distance from radioactive and other radiation sources. (Distance is a particularly effective way of minimizing one's radiation dose because of the "inverse-square law" [6] (Table 3.5).)
- Maximize shielding of radioactive and other radiation sources.

Distance from patient, *cm*	Imaging duration, *min*	Exposure (mR)	
		Thallium-201 3.5 mCi	Technetium-99m 30 mCi
1	40	1600	14,000
5	40	65	560
15	40	7.0	60
30	40	1.8	16
100	40	0.20	1.4

Adapted from Limacher et al. [6]; with permission from Elsevier

Table 3.5 Effect of distance from patient on exposure from radioisotopes commonly used in nuclear cardiology

Consistent with the "As-Low-as-Reasonably-Achievable (ALARA)" concept, these measures should be implemented to the extent that is practical and in a manner that does not compromise patient care. (For example, avoid rushing through the preparation and assay of a radiopharmaceutical, which potentially might result in a misadministration.) Radiopharmacies and other work areas where unsealed radioactive materials are handled should be provided with appropriate radiation safety supplies and equipment (Table 3.6 and Figs. 3.2, 3.3, 3.4, 3.5, and 3.6).

"Radiation" signage (Fig. 3.2)
Lead shields (fixed or mobile) with lead glass windows—For x-ray and gamma-ray emitters (Fig. 3.3)
Plastic shields—For beta emitters[a] (*see* Fig. 3.3)
Plastic-backed absorbent pads and/or drip trays, to contain any spills (*see* Fig. 3.3)
Syringe shields with see-through windows (*see* Fig. 3.3)
Shielded carriers—For transporting activity-containing syringes or other small sources (*see* Fig. 3.3)
Dose calibrators—To assay patient radiopharmaceutical activities and other radioactive sources (Fig. 3.4)
Personnel dosimeters (Fig. 3.5)
Tongs or forceps, to maximize the distance of the worker and the worker's hands from manually handled radioactive sources
Waste receptacles
A shielded receptacle with removable plastic lining (plastic bag) for dry waste
A shielded puncture-proof receptacle for needles and other "sharps" waste
Radiation and radioactive contamination monitoring equipment: Geiger counter for exposure-rate measurements, solid-state survey meter for assay of radioactive waste, and scintillation well counter for assay of wipes used to check for removable contamination (Fig. 3.6)
Fume hood, for working with volatile or other potentially airborne radioactive materials[a]
Personnel protective equipment (PPE)
Laboratory coat or disposable gown
Disposable waterproof gloves
Face shield—Where a risk of splatter of radioactive liquid or droplets exists[a]
Face mask—Where a risk of airborne droplets exists[a]
Shoe covers (booties)—Where radioactive contamination of the floor exists or realistically may occur[a]
Radioactive materials log/inventory (hardcopy or computerized)—To record receipt, distribution, and disposal of each radioactive material

[a]Generally not required in nuclear cardiology

Table 3.6 Basic radiation safety supplies and equipment

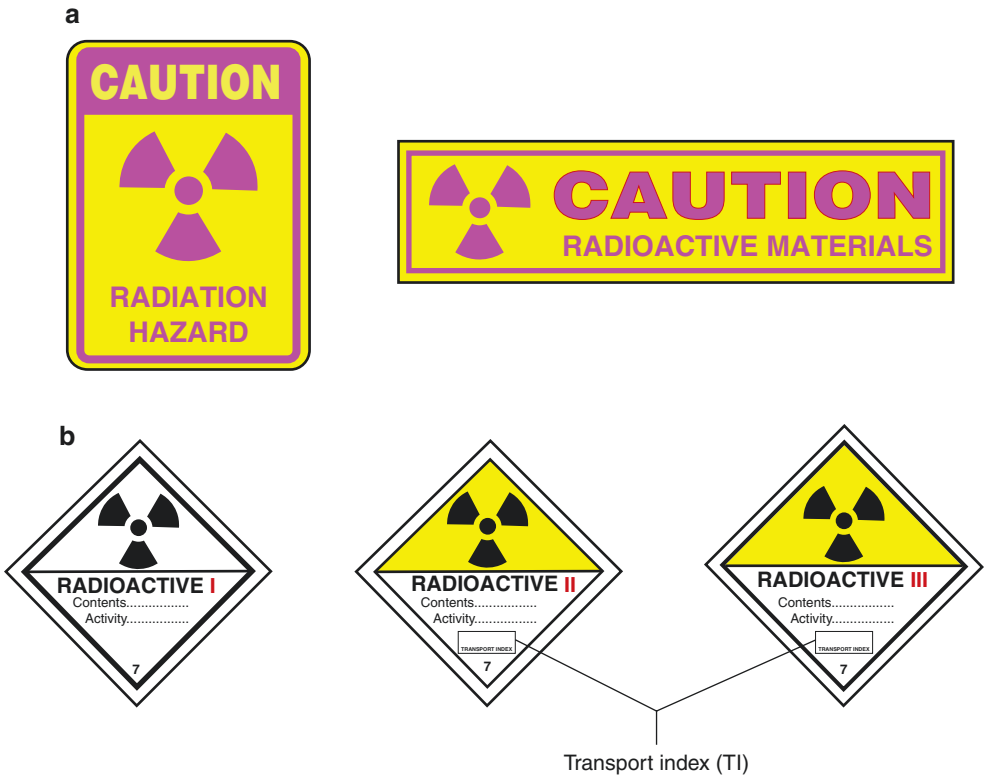


Fig. 3.2 (**a**) Radiation protection signage, including the familiar purple trefoil on yellow background. For purposes of radiation protection, nuclear cardiology and other nuclear facilities designate certain sites within the facility as "restricted" areas. A restricted area is any area to which access is controlled to protect individuals from exposure to radiation and radioactive materials. The regulatory dose limits for occupationally exposed individuals apply in a restricted area, so entry of non-occupationally exposed individuals into such an area should be controlled by a physical barrier (such as a locked door) and appropriate signage, as shown in this figure. Restricted areas include any areas where radioactive materials are used and stored; these areas require the "Caution – Radioactive Materials" signage in addition to or in place of the "Caution – Radiation Hazard" signage. In addition to restricted areas, a nuclear facility may designate sites within the facility as "controlled" areas, defined as an area outside a restricted area but within the facility boundary to which the facility can limit access for any reason. A controlled area (such an office in which sensitive information is filed) requires a physical barrier but not radiation-precaution signage. (**b**) Department of Transportation (DOT)–required signage for shipment of packages containing radioactive materials [3]. The transport index (TI) is the exposure rate (in milliroentgens per hour, mR/h) measured at a distance of 1 m from the surface of the package. Low-activity (*ie* "White 1") packages have an immeasurably low exposure rate at 1 and thus do not require a TI entry on the label

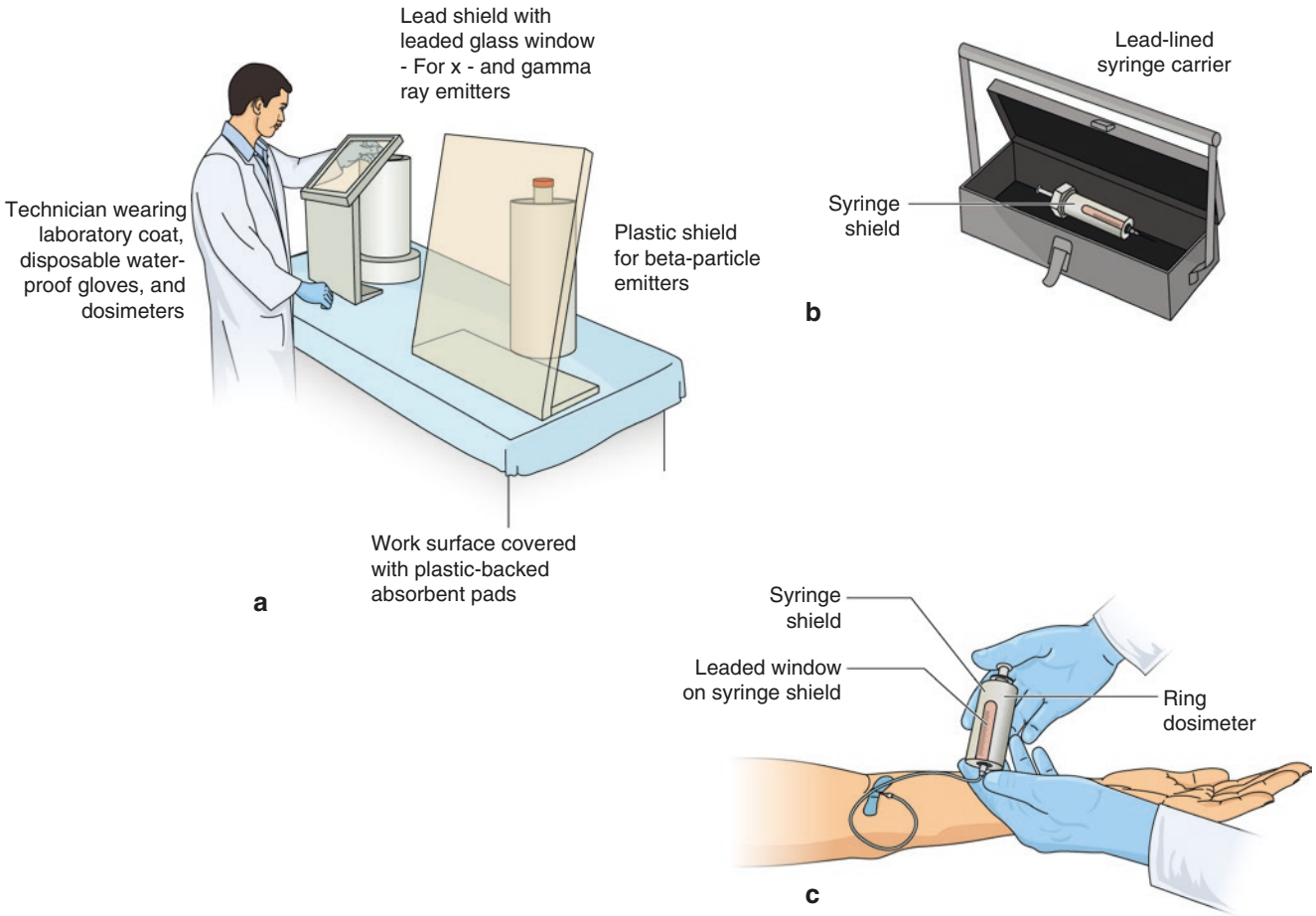
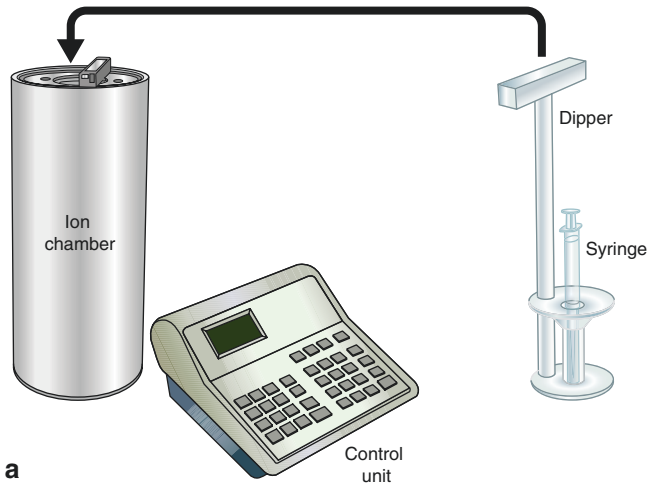
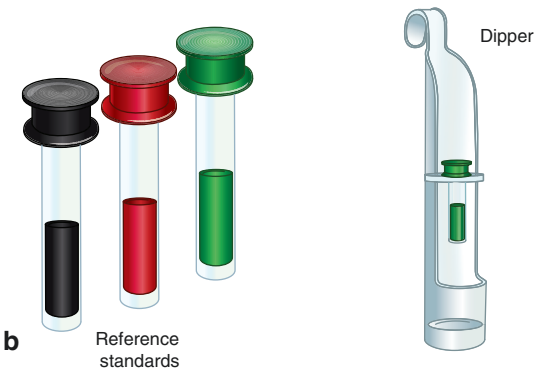


Fig. 3.3 (**a**) Set-up for working with unsealed sources of radioactivity, as detailed in Tables 3.3 and 3.4. A lead shield with a leaded glass window (sometimes called an "L shield") is required to adequately attenuate x-rays and gamma rays, as the attenuation of such highly penetrating photons increases with increasing atomic number and mass density of the stopping medium. Beta particles, on the other hand, are nonpenetrating radiations that are adequately attenuated by a thickness of plastic. The use of plastic as shielding for beta particles, rather than lead or other materials with a high atomic number, minimizes the possible production of *bremsstrahlung* ("brake radiation") x-rays, as *bremsstrahlung* production increases sharply with the increasing atomic number of the stopping medium. (**b**) Radiopharmaceutical syringe in a syringe shield in place in an opened lead-lined carrier used for transport. (**c**) Intravenous injection of a radiopharmaceutical with the syringe in place in a syringe shield. Note that a ring dosimeter is required on a finger of the individual performing the injection





Radioisotope	Half-life	Energy of principal X- or gamma ray
Cobalt-60	272 d	122 kev
Barium-133	10.7 y	356 kev
Germanium-68	287 d	511 kev

Cobalt-57, barium-133, and germanium-68 are sometimes known as "mock" technetium-99m (gamma-ray energy: 140 keV), iodine-131 (364 keV), and fluorine-18 (511 keV), respectively.

Fig. 3.4 (**a**) The dose calibrator, an ionization chamber with a sealed-gas detector and a well-type geometry, is used to assay the activity (in units such as mCi or MBq) in a radiopharmaceutical syringe or other small radioactive source. The syringe is placed in a plastic dipper and the dipper is then used to lower the syringe into position for assay. The radioisotope is selected by pressing the corresponding button on the control panel. For some older models, the user selects "Other" and adjusts the setting of a potentiometer dial to a manufacturer-specified value for the specific radioisotope for those isotopes for which a button is not provided. For newer models, a computerized control unit with a computer screen and soft keys is provided. (**b**) Routine (daily) quality control of dose calibrators is essential to ensure that patients receive the correct activity of the prescribed radiopharmaceutical. This is generally performed using commercially available, long-lived National Institute of Standards and Technology (NIST)–traceable reference standards, that is, radioisotopes whose gamma-ray and/or x-ray energies approximate those of radioisotopes commonly used in clinical studies. Among quality control tests, constancy must be checked daily, and accuracy and linearity at least quarterly, but daily checks of accuracy are recommended. For the constancy test, an NIST-traceable reference standard, such as cobalt-57, barium-133, and/or germanium-68 is placed in the dose calibrator and the activity reading on each scale is recorded; day-to-day readings should agree within 10%. For the accuracy test (also sometimes known as the "energy linearity" test), at least two of the foregoing NIST-traceable reference sources are separately placed in the dose calibrator and the activity reading on each activity scale is recorded. For each source, the measured activity on each scale and its current actual activity should agree within 10%. Like all sealed sources, reference standards should be wipe-tested for removable contamination (*ie*, leak-tested) quarterly. The linearity test is described in Zanzonico [12]

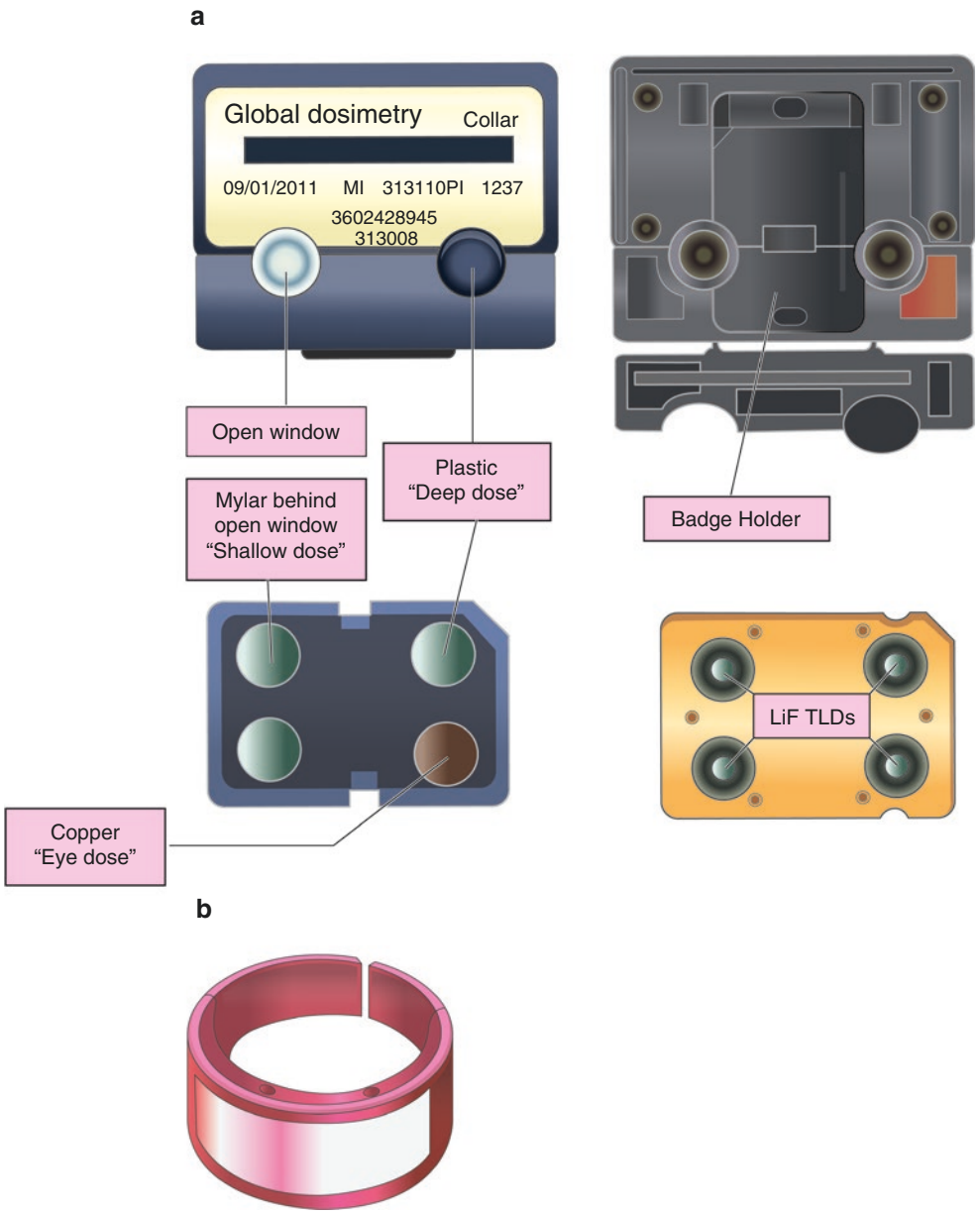


Fig. 3.5 Personnel radiation dosimeters. (**a**) The dosimeter pictured includes up to four individual lithium fluoride (LiF) thermoluminescent dosimeters (TLDs). The TLDs are each covered by a specific filter to simulate the attenuation of incident radiation by different thicknesses of tissue and thereby yield estimates of the radiation dose at specific depths: Mylar (area density: 7 mg/cm^2) to yield the skin ("shallow") dose at a depth of 0.007 cm; copper (300 mg/cm^2) to yield the lens-of-eye dose at a depth of 0.3 cm; and polypropylene plastic (1000 mg/cm^2) to yield deep ("organ") doses at a depth of 1.0 cm. TLDs are essentially storage phosphors in which electrons are raised to excited energy states by the incident radiation, a fraction of which remains trapped in these excited states. When the dosimeters are subsequently heated, these trapped electrons are released and return to their ground state, with the emission of light. The amount of light emitted is related to the number of trapped electrons and, in turn, to the radiation doses delivered to the TLD. Optically stimulated luminance (OSL) dosimeters, composed of crystalline aluminum oxide activated with carbon (AL_2O_3:C), are now used as an alternative to TLDs. OSL dosimeters work in a similar manner to TLDs except that laser light rather than heat frees the trapped electrons. In the past, personnel dosimeters used photographic film; the radiation-induced blackening (*ie*, optical density) of the film was directly related to the radiation dose. Personnel dosimeters can record doses from as low as about 10 mrem (0.1 mSv) to about 1000 rem (10 Sv). Though film-based dosimeters provide a permanent dose record, the fact that TLDs and OSL dosimeters are reusable offers significant cost savings, so most personnel dosimeters are now TLDs or OSL dosimeters. A dosimeter such as the one pictured (sometimes referred to as a "body badge" dosimeter) is typically worn at the level of the collar. (**b**) A ring dosimeter. Such a dosimeter is especially important for radiopharmacists and for personnel who inject or otherwise manually handle radiopharmaceutical syringes and other radioactive sources. As shown in Table 3.2, the hand doses to such personnel can be significant [13]

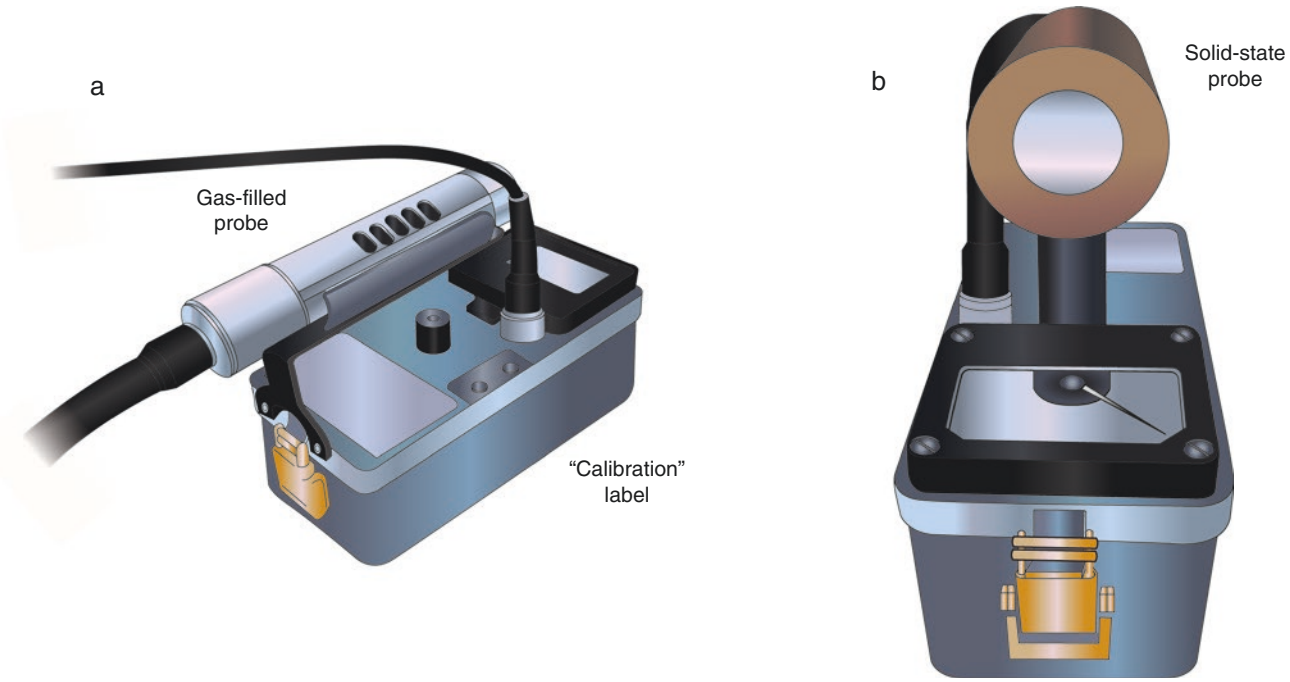


Fig. 3.6 Survey meters. (**a**) The Geiger counter (also known as a Geiger-Muller, or GM, counter) is a gas-filled ionization detector widely used to measure ambient exposure rates. It should provide a readout in terms of absolute exposure-rate units (such as mR/h) and not simply in terms of count rate (such as counts per minute, cpm). Exposure-rate measurements should be performed daily in all areas where radiopharmaceuticals are prepared, assayed, or administered; weekly in all areas where radioactive materials are otherwise used or are stored, including radioactive-waste storage areas; and quarterly in all areas where sealed radioactive sources are stored [2, 5]. Ambient exposure rates should not exceed 0.1 mR/h in unrestricted areas and 5 mR/h in restricted areas [2, 5]. If these exposure rates are exceeded, corrective action (such as the use of additional shielding) should be taken. Survey meters should be calibrated annually and a dated calibration label affixed to the meter. Surface contamination levels, checked by assaying dry wipes of potentially contaminated surfaces in a scintillation well counter, should be less than 200 disintegrations per minute (dpm)/100 cm^2 in unrestricted areas and less than 2000 to 20,000 dpm/100 cm^2 (depending on the radioisotopes in use) in restricted areas [2, 5]. If these contamination levels are exceeded, corrective action (*ie*, decontamination) should be taken. (**b**) Although grossly similar in appearance to the Geiger counter, a solid-state survey meter uses a solid detection medium and therefore provides far greater sensitivity than the gas detector–based Geiger counter. The solid-state survey meter is better suited, therefore, for assay of radioactive waste, because its higher sensitivity makes it less likely that such waste will be inadvertently routed to the general waste stream before it has decayed "completely" (*ie*, to undetectable low activities). In practice, radioactive waste being held for decay in storage should *not* be routed to the general waste stream until the count rate measured at the surface of the waste container is no greater than the background count rate. However, solid-state survey meters are not calibrated to provide readouts in terms of absolute exposure rates (*eg*, in units of mR/h) and therefore cannot be used for exposure-rate measurements

Standard lead aprons, 0.25 or 0.5 mm in thickness, are designed to provide shielding for diagnostic x-rays in general and for scattered x-rays in particular (with average energies typically well under 100 keV); they are of course required for fluoroscopy personnel. A 0.5 mm-thick lead apron is approximately equivalent to two half-value layers for the scattered radiation associated with a 100-kV x-ray beam, for example, and thereby reduces the dose by about 75% [9, 10]. Lead aprons 0.5 mm in thickness can also attenuate over 60% of thallium-201 and technetium-99m photon radiations (68–83 and 140 keV in energy, respectively) and hypothetically may reduce thallium-201 and technetium-99m personnel exposures by over 60% if worn for all such procedures [9, 10]. However, lead aprons provide no significant attenuation or dose reduction (less than 10%) for the 511-keV gamma rays encountered in positron emission tomorgraphy (PET) [9, 10]. Although the use of lead aprons in nuclear cardiology and nuclear medicine is not a widespread practice and is generally not recommended, a pregnant individual who works exclusively with thallium-201 and technetium-99m may consider wearing a lead apron during her pregnancy.

When working with radiopharmaceuticals and other unsealed sources of radioactivity, the possibility of spills exists. The emergency procedures for dealing with spills of radioactive materials differ depending upon whether the spill is a minor or a major spill [5]; the procedures are detailed in Table 3.7.

Notify all personnel in room that a spill has occurred and instruct all uninvolved individuals to exit the area
Restrict entry to room
Don two pairs of disposable waterproof gloves (so that the outer, contaminated gloves can be removed and replaced while avoiding hand contamination)
Upright the container from which the spill occurred
Cover the spill with absorbent sheets having a water-impermeable plastic coating with the absorbent side facing the spill
For a minor spill, proceed to the next steps
For a major spill or if in doubt as to the severity of a spill or how to proceed, contact the institutional Radiation Safety Office for further remediation
Spills of technetium-99m >100 mCi, indium-111 >10 mCi, and thallium-201 >100 mCi are considered major; spills of lesser activities of these radioisotopes are considered minor [2]
Decontaminate the area, discarding clean-up materials in a plastic bag for disposal as radioactive waste
Wipe the spilled liquid towards the center of the spill area with dry paper toweling, then with moist paper toweling, and then with dry paper toweling, taking care not to flood the area and spread the spill
Survey the spill area, clothes, and hands and feet
Use a survey meter for radioisotopes emitting gamma rays or x-rays
Use wipe testing for a pure beta particle–emitting radioisotope
Contaminated shoes and clothing should be removed, placed in plastic bags, appropriately labeled, and held for decay in storage
As a rule of thumb, continue decontamination until the results of the post-contamination surveys are no greater than twice the background count rate. If this level of decontamination cannot be achieved, the contaminated area may need to be shielded with lead and labeled as "contaminated" until the remaining radioactivity is eliminated by physical decay
Report the spill and remedial actions taken to the institutional Radiation Safety Office

Table 3.7 Emergency procedure for radioactive spills

In summary, the use of unsealed sources of radioactivity in nuclear cardiology results in finite radiation doses to personnel. However, with careful implementation of basic radiation safety measures, the doses to nuclear cardiology personnel are generally very low—an order of magnitude lower than the regulatory dose limit for occupationally exposed individuals and even lower than the dose limit for non–occupationally exposed individuals [2, 7, 8].

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