Chapter 25

Hospital Responses to Radiation Casualties

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Introduction

Awareness of the need for advanced preparation of hospitals in anticipation of possibly dealing with radiological emergencies has been reemphasized as a consequence of recent world events. Emergency department (ED) resources are necessary for the treatment of patients suffering from injuries in combination with possible radiation contamination or exposure (combined injuries). Until recently, there were few options available for in-service training tools for educating ED staff in the evaluation and treatment of such victims. A 45-min PowerPoint presentation entitled "Emergency Department Management of Radiation Casualties," prepared by the Radiological Emergency Medical Preparedness and Management subcommittee of the Health Physics Society's Ad Hoc Committee on Homeland Security, was designed to help educate ED staff on the management of radiation casualties in the case of a radiological event. A manuscript augmenting the information presented in the training module, which was released in early 2003 (http://hps.org/hsc/emergency.ppt), will be published in an emergency medicine journal shortly. The goal of this training is to provide a basic overview of the most important issues in an effort to raise the level of comfort and lower the level of anxiety of ED staff who may be called upon to treat these types of patients. The training covers the following topics:

- Characteristics of ionizing radiation and radioactive materials
- Differentiation between radiation exposure and radioactive material contamination
- Causes of radiation exposure and contamination
- Staff radiation protection procedures and practices
- Facility preparation
- Patient assessment and management of radioactive material contamination and radiation injuries
- Health effects of radiation exposure
- Facility recovery
- Resources

This information is available online at: http://hps.org/hsc/emergency.ppt. Each slide is accompanied by talking points that give further details and explanations that can be used when conducting training sessions. The presentation emphasizes that the priority of medical management of traumatic injuries outweighs the concerns over radiation-related issues. It stresses how using "universal precautions" (i.e., the use of protective barriers such as gloves, gowns, aprons, masks, or protective eyewear to reduce the risk of exposure of the healthcare worker's skin or mucous membranes to potentially contaminating materials) provides adequate protection to the staff, thus allowing medical stabilization of the patients. Educating medical staff on the actual magnitude of the radiological hazards will allow them to promptly and confidently provide patient care without undue concern for their own safety or ED facility contamination. The topics covered are basic radiation terminology, patient management issues and priorities, decontamination procedures, facility issues, and the effects and risks of radiation exposure and contamination.

Our goal in presenting this information to health physics professionals is to provide you with additional tools to assist you in your role as educators and promoters of good radiation safety practices. Some of the information presented herein is well known to you. It is our intention to simply provide the information in a format that will facilitate communication with non-radiation professionals in the medical community.

Characteristics of Ionizing Radiation and Radioactive Materials

The first section of the program includes descriptions of ionizing radiation, radiation units, doses, dose limits, radioactive material, and half-life. The radiation units are shown in Table 25.1. Although SI units are used by professionals in radiation protection, most instruments and many labels on sources of radioactive material still use conventional units.

Differentiation Between Radiation Exposure and Radioactive Material Contamination

An explanation of the difference between radiation exposure and radioactive contamination is an important concept for the ED staff to understand (Miller 1986). Radioactive contamination can be explained simply as radioactive material (often attached to dust or dirt) that is in an unwanted location. In the case of an accident victim, it may be either on the skin or clothes of the person or may have been taken into the body via inhalation or ingestion or through a wound. Contaminated patients require careful handling to effectively remove and control the contamination. Usually, most of the external contamination can be removed from patients by carefully removing their clothing. Patients who have only been exposed to radiation from a radioactive source or a machine, such as an x-ray ma-

Table 25.1. Radiation units.[a]

Measurement	Quantity	Unit
Amount of radioactive material	Activity	curie (Ci)
Ionization in air	Exposure	roentgen (R)
Absorbed energy per mass	Absorbed dose	rad
Absorbed dose weighted by type of radiation	Dose equivalent	rem

[a]For most types of radiation, 1R = 1 rad = 1 rem.

chine or a linear accelerator, are not contaminated and do not pose any hazard to hospital personnel. Radiation safety precautions are not needed for patients who have only been exposed and are not contaminated.

One way to explain the difference in these two terms is to use an example of a trip to the beach. Sand can be likened to radioactive material and the sun to radiation exposure. Once you go inside, you are no longer in the sun and there is no more exposure (the radiation stops). On the other hand, while most of the sand will come off when you walk off the beach, some sand remains on your skin until you physically remove it (brush or wash it off). The same is true for radioactive material on the skin. A small amount may remain on the skin and need to be washed off.

Causes of Radiation Exposure and Contamination

There are several settings or scenarios in which radiation accidents and emergencies may occur. Some examples include medical radiation therapy accidents; accidental overexposures from industrial irradiators; lost, stolen, or misused medical or industrial radioactive sources; accidents during the transportation of radioactive material; and nuclear reactor accidents (Weidner et al. 1980; Miller 1994). Worldwide, there were 428 reported radiation accidents between 1944 and 2002, from which 126 deaths occurred due to radiation (REAC/TS 2002). The impacts of these accidents were dependent on the magnitude of the radiation exposure, contamination, and the number of individuals involved. Though these types of accidents are relatively rare, heightened awareness of the potential impact from terrorist activity has stimulated many hospitals to reassess their needs for a radiological emergency response plan and training.

The use of radioactive materials in a radiological dispersal device (RDD) or a nuclear weapon by a terrorist is a remote but possible threat. An RDD (sometimes called a "dirty bomb") is not an atomic bomb. An RDD is formed by combining a conventional explosive (e.g., dynamite or a plastic explosive) with radioactive material. While the initial explosion may kill or injure those closest to the bomb, the radioactive material that is dispersed will likely expose and contaminate survivors and emergency responders. Due to the dilution effect of such an explosion, it is unlikely that the exposure or contamination of people outside of the immediate blast area will have any clinical impact beyond the psychological impact from the fear of radiation. The nuclides that are considered to be the most likely to be used in an RDD are ^{137}Cs, ^{60}Co, ^{239}Pu, ^{192}Ir, ^{90}Sr, and ^{241}Am. Detonation of a low-yield nuclear weapon or partial failure of a high-yield weapon in a populated area would result in extensive loss of life and contamination.

Fortunately, there have been no RDD (dirty bomb) or low-yield nuclear weapon detonations by terrorists. However, the materials to produce an RDD have been intercepted by law enforcement in the past. The medical consequences of such events would depend on the type of device used, size of the explosion (or yield), the type of radioactive material involved, the activity (amount) of the radioactive material, the number of people in the vicinity, and the effectiveness of the emergency response.

Staff Radiation Protection Procedures and Practices

Maintaining radiation exposure and contamination at levels that are as low as reasonably achievable (ALARA) is the goal. Methods to accomplish this goal are discussed in the following sections.

Reducing Exposure

There are three methods for reducing radiation exposure: time, distance, and shielding. All three of these methods can be used to keep radiation exposure to a minimum. Hospital staff are well versed in protecting themselves and their work areas from microbiological contamination through the use of "universal precautions." The same techniques can be used effectively to protect personnel and the work area from contamination by radioactive materials. Staff protect themselves from contamination by using universal precautions and double-gloving.

Detection

Radiation monitoring instruments are very sensitive and able to detect the presence of radiation at very low levels. The radiation measured is usually expressed as exposure per unit time, using various units of measure including milliroentgen per hour (mR h^{-1}) and counts per minute (cpm). It is important to keep in mind that any value (reading) with "milli" or "micro" in front of it is small. The most commonly used instruments to detect the presence of radiation are the Geiger-Mueller (GM) survey meter (also known as a Geiger counter) and the ionization chamber. The GM survey meter will detect low levels of gamma and most beta radiation and typically has the capability of distinguishing between the two. It is used to quickly determine whether a person is contaminated. Since the GM survey meter is so sensitive, other instruments may be needed to measure higher levels of contamination.

Ionization chamber survey meters can accurately measure radiation exposure. These meters measure radiation exposure from low levels (mR h^{-1}) to higher levels (R h^{-1}). To determine the radiation dose an individual has actually received, it is necessary to correct for the amount of time that he or she was exposed. When caring for a contaminated patient, if the ionization chamber is reading 5 mR h^{-1}, the staff would need to be standing in that

Table 25.2. Typical radiation doses.

Flight from Los Angeles to New York	2.5 mrem
Chest x-ray	5 mrem
Annual natural background in United States	300 mrem
Bone scan	400 mrem
Abdominal CT	760 mrem
Barium enema	870 mrem
Cardiac catheterization	45,000 mrem

location (next to the patient, the source of radiation) for 1 h to receive 5 mR. In many situations, ED staff spend much less than an hour with any individual patient. For example, if staff members spent 15 min in close proximity to a patient where the exposure rate was 5 mR h^{-1}, they would only receive 1.25 mR, less than the radiation dose received from cosmic radiation during a cross-country airplane flight. Examples of some typical radiation doses are listed in Table 25.2.

Personal dosimeters are devices that measure the cumulative dose of radiation received by the person wearing them. They are available in two types: badges (containing film, thermoluminescent dosimeter [TLD] material, or other radiation-detecting material) and self-reading dosimeters. Film or TLD badges must be analyzed by the company that supplies them and so the radiation dose received is not known for several days. Self-reading dosimeters allow their wearers to see the total radiation doses they have received at any time.

Table 25.3. Facility preparation.

Activate hospital plan	Obtain radiation survey meters Call for additional support; staff from nuclear medicine, radiation oncology, radiation safety (health physics) Establish triage area Establish area for decontamination of uninjured persons Instruct staff to use universal precautions
Plan to control contamination	Establish multiple receptacles for contaminated waste Protect the floor with covering (only if time permits) Universal precautions and double-glove
Protect staff from contamination	Survey hands and clothing with radiation survey meter Replace gloves and gowns if contaminated and between patients Keep the areas outside the decontamination/treatment area free from contamination

Facility Preparation

The hospital should have a well-thought-out radiological emergency medical response plan that can be tested periodically through drills. An excellent resource for plan design is the National Council on Radiation Protection and Measurements' (NCRP) Report No. 138, "Management of Terrorist Events Involving Radioactive Material" (NCRP 2001). It contains a section specific to the medical management of radiation casualties from on-scene triage through medical follow-up. In addition, the Centers for Disease Control and Prevention (CDC) recently released the "Interim Guidelines for Hospital Response to Mass Casualties from a Radiological Incident" which also contains valuable information and references (CDC 2003). The specific plan developed by each hospital should address contamination control for staff and facilities, including control and survey of materials and personnel coming into and leaving the area (Table 25.3). Actual facility preparation will depend on the amount of notification the ED receives prior to patient arrival as well as the number of patients anticipated to be received. In situations involving other types of hazardous materials, such as chemicals and biohazards, decontamination of the victims is usually required prior to transportation. This concept is embedded in current NBC (nuclear, biological, chemical) training for first responders and ED staff. However, in the case of radioactively contaminated victims, there is little chance of harm to the emergency responders. The hospital plan should specifically address the issue of hospital policy regarding entry of patients with radioactive contamination into the ED. EMTs will attempt to decontaminate the victims in the field, but medical management should be the first priority. Typically, 90% of radioactive contamination is removed when the clothes are removed (AFRRI 1999). What little remains will stay in place if the patient is wrapped in a sheet and then transported.

There should be a call-out list to notify the staff on hand that a radioactively contaminated patient is headed to the ED, as well as to obtain additional staff and equipment that will be needed under such circumstances. Staff should know where to obtain radiation survey meters and what personnel know how to operate them. The additional support for the ED could come from hospital staff in departments such as nuclear medicine, radiation oncology, or radiation safety/ health physics. If radiation safety personnel are available at the facility, they will be a valuable asset in the management of the flow of people through the ED. They can perform whole-body surveys of the accident victims, allow for more efficient triage of the patients, and provide for radiation dose assessment (Toohey 2002). Diligent use of survey meters will help prevent the spread of contamination (e.g., survey gloves and change as necessary, survey shoes when leaving, etc.). Radiation safety personnel can perform the following tasks:

- Assist with facility preparation of controlled areas for patient assessment and treatment
- Perform radiation surveys of patients as they enter the ED
- Aid in differentiation between radiation exposure and radioactive material contamination
- Collect samples from patients, if possible, and provide analysis to identify radionuclides

- Serve as a resource for staff radiation protection questions regarding procedures and practices
- Provide resources to physicians regarding the management of radiation injuries
- Aid in decontamination of patients if necessary and requested
- Monitor area to identify extent of radiation exposure and contamination
- Perform bioassays on patients and staff if warranted
- Survey patients and staff as they transition out of contaminated areas of the ED
- Assist the ancillary staff with facility recovery

A critical point that needs to be emphasized whenever communicating with ED/EMT personnel is that the medical care of the patient takes priority over decontamination. Experiences with contaminated and injured patients show that precautions taken as described in this chapter are adequate to prevent significant risk to medical staff (see related chapters). Such experiences can be cited to reluctant staff in training sessions to alleviate fears prior to the need to manage radioactive patients. Resuscitation and stabilization are the primary objectives. Decontamination efforts should be secondary to patient stabilization.

A triage area should be identified. In this area, assessment can be made as to whether the person needs to be seen in the ED (Weidner et al. 1980; Miller 1990; AFRRI 1999; NCRP 2001). A mass-casualty incident resulting from a terrorism event involving radioactive material is likely to generate large numbers of frightened people (AFRRI 1999; NCRP 2001) who may not require trauma care. A plan for evaluation and possible decontamination of uninjured persons away from the ED should be established in advance so that the ED is not inundated with uninjured people. To reassure these psychological casualties ("worried well") and prevent them from overwhelming healthcare facilities, radiation survey and counseling centers should be established. These centers should each be staffed by physicians with a radiology background, health physicists with survey meters, and psychological counselors. In addition, the hospital should plan to provide psychological support to patients and set up a center in the hospital for counseling the staff. (Other chapters in this book provide further information and references on managing psychological trauma.)

The layout in the ED for the handling of a contaminated radiation accident victim (NCRP 1979; Weidner et al. 1980; DeMuth and Miller 1982; Miller and Weidner 1982; Donovan et al. 1983; Miller and DeMuth 1983; Miller 1990; Mettler 2001) should be established in a manner that will control the spread of contamination. The plan should describe an approach to protecting the floor and equipment with covering, but only if time allows for such an activity. Multiple receptacles for contaminated waste should be established to prevent the spread of contamination outside of the ED. Compared to chemical and biological hazards, one advantage that care providers have, when it comes to radioactive contamination, is the ease with which radioactive material can be detected. Most radioactive material can be detected easily and in very small quantities through the use of a GM survey meter (Geiger counter). Frequent use of the GM survey meter can alert personnel of the need to change their gloves or clothing when they become contaminated or to alert them when contamination is being spread to the work area so that cleanup and extra precautions can be implemented. Such ease of detection and control is not possible with any other types of hazardous material.

Patient Assessment and Management of Radioactive Material Contamination and Radiation Injuries

Patient Assessment

The following key points should be kept in mind when managing patients:

- Medical triage is the highest priority. Triage is based on: (1) injuries; (2) signs and symptoms (nausea, vomiting, fatigue, diarrhea); (3) history: where was the patient when he or she was exposed?; and (4) contamination survey.
- Radiation exposure and contamination are secondary considerations.
- Degree of decontamination is dictated by the number of and capacity to treat other injured patients.
- Contamination is easy to detect and most of it can be removed once the patient is stabilized.
- Injured, contaminated patients should be transported from the ED by transferring them to a clean gurney and wrapping them in a sheet.
- It is very unlikely that ED staff will receive a large radiation dose from treating contaminated patients.

After the victim enters the ED, obtaining the patient's history will further assist in the triage process to predict the potential extent of radiation injury (Miller and DeMuth 1983; Mettler 2001). Questions about the circumstances surrounding the injury, as well as a G-M survey of the patient, will provide valuable patient management information. Though contamination surveys are secondary to patient stabilization, they should be conducted when possible. In the case of an RDD, exceptional dose rates could exist if embedded shrapnel from the RDD was intensely radioactive. This remote possibility would be easy to determine with appropriate radiation survey equipment. If foreign objects or debris are removed from the wound or skin, they should be transferred to lead containers (pigs). Specimens collected for medical assessment during this survey can yield valuable information for treatment planning (Table 25.4). Samples should be placed in bags and labeled with the patient's name, date, and time of sample collection, sample location, and the size of the area sampled. Though nausea and vomiting are signs of high radiation dose exposure, such an exposure from a RDD is unlikely. Consequently, if such symptoms are present, they are likely psychological in nature.

Decontamination should commence after stabilization of the patient. Following is a step-by-step decontamination procedure:

- Do not delay emergency surgery or other necessary medical procedures or exams; residual contamination can be controlled.
- Carefully remove and bag patient's clothing and personal belongings (typically removes 90% of contamination).
- Survey patient and, if practical, collect samples.

Table 25.4. Specimens to be collected for medical assessment of a patient exposed to radiation.

Specimen/type of analysis	Reason for obtaining	Mechanism for obtaining
In All Cases of Radiation Injury		
Blood: CBC with differential lymphocyte count, repeated every 6 h for 48 h if possibility of total body irradiation	To establish a baseline count from which subsequent counts can be compared; assess radiation dose received by patient	Venipuncture in uncontaminated area into purple top tube containing EDTA; cover puncture site
Blood: Chromosomal analysis	Chromosomal analyses provide another way to estimate the radiation dose. Specialized labs are required. Results are not available immediately.	Venipuncture in uncontaminated area into dark green top tubes (sodium heparin tube) [light green top tubes (lithium heparin with gel) are not acceptable]; cover puncture site
Urine: Routine urinalysis	Determine normal kidney function and baseline for urinary constituents; especially important if internal contamination is suspected	Avoid contamination when collecting sample; label sample with date and time of collection
When External Contamination is Suspected		
Nose, ear, mouth: Swab body orifices; analyze with GM probe, gamma counter, LSC, or MCA if available	Assess the possibility of internal contamination and identify the radionuclide	Use separate saline- or water-moistened swabs to wipe the inside of each nostril, ear, and mouth. Label and bag separately.
Wounds: Samples from dressings or swabs of wounds	Assess whether wounds are contaminated and identify the radionuclide	Save dressings as they are changed; use swabs to sample the secretions from wounds; if foreign objects or debris are removed, transfer them to lead containers (pigs)
When Internal Contamination is Suspected		
Urine bioassay: 24-h specimen; repeat for 4 d	Body excreta may contain radionuclides if internal contamination has occurred	Standard specimen containers
Feces bioassay: 24-h specimen; repeat for 4 d		

- Handle foreign objects with care until they are proven nonradioactive with a survey meter
- Priorities: (1) decontaminate wounds first, then intact skin; (2) start with the highest levels of contamination; (3) protect uncontaminated wounds with waterproof dressings; (4) irrigate and gently scrub with a surgical sponge; (5) extend wound debridement for removal of contamination only in extreme cases and upon expert advice; (6) change dressings frequently.
- Decontaminate thermal burns by gently rinsing. Aggressive washing may increase the severity of injury.
- Additional contamination will be removed when dressings are changed.
- Decontaminate intact skin and hair by washing with soap and water.
- Remove stubborn contamination on hair by cutting with scissors or electric clippers.
- Promote sweating.
- Avoid overly aggressive decontamination.
- Cease decontamination of skin and wounds when the area is less than twice background, or when there is no significant reduction between decontamination efforts, and before the skin becomes abraded.
- Change outer gloves frequently to minimize spread of contamination.
- Use survey meter and body survey charts to monitor progress of decontamination.

To reiterate, removal of clothing, which usually occurs in the field prior to transportation to the hospital, has been found to reduce the contamination on the patient by approximately 90%. Unfamiliar embedded objects in patients' clothing or wounds may be radioactive sources. Such objects should be handled with long forceps, as quickly as possible, keeping them distant from staff and patients until they are proven, with a survey meter, not to be radioactive. If radioactive objects are recovered, they should be placed in a lead container (readily available in nuclear medicine departments) using tongs or forceps. If the patient remains contaminated after removal of his or her clothes, uncontaminated wounds should be protected with waterproof dressings to minimize the potential for uptake of radioactive material during decontamination efforts.

Usual washing methods are effective for removal of radioactive contamination. Contaminated waste water need not be contained if it will unduly complicate the treatment of the patient or if it is otherwise determined to be impractical. Release of waste water can be justified in almost all situations and can be addressed after care for the patients is completed. Under no circumstances should efforts at decontamination cause the skin to become abraded. Openings in the skin allow increased absorption of radioactive material. If an area of contaminated skin persists, the area should be covered with gauze and a glove or plastic to promote sweating. Sweating can remove radioactive material from pores. Contaminated hair can be removed, if necessary, using scissors or electric clippers. To avoid cutting the skin and providing an entry for internal contamination, shaving should be avoided.

To decontaminate wounds, irrigate with tepid water and gently wash with soap and a surgical sponge or gauze pad. Normal wound debridement should be performed. Excision around wounds solely to remove contamination should only be performed in extreme cases and upon the advice of radiological emergency medical experts. Often radioactive material will exude from wounds into gauze dressings, so frequent changing of dressings may aid wound decontamination. The dressing also serves to keep the contamination from spreading. Contaminated thermal burns can be gently rinsed while ensuring that there will be no further damage to the skin. Additional contamination will be removed with the exudate as dressings are changed. Cease decontamination of the skin and wounds when the area is less than twice the background reading on the survey meter or if there is no significant reduction between washes. (Higher release rates from decontamination might need to be used if an overwhelming number of persons are to be triaged, or if undue fear of contamination must be avoided. On the average, for fission product contamination, it is generally high-sided to assume that a skin contamination level of 1 nCi cm^{-2} of material emitting about one beta ray per transition will deliver a skin dose rate of no more than 9 mrad h^{-1}. With a pancake GM probe, 1 nCi cm^{-2} would produce a count rate for each square centimeter of open window of about 1,000 counts per minute above background at about 50% geometry. Normal washing and skin replacement over time will reduce such a skin contamination level so that no harmful skin effects should occur. See experiences cited in other chapters and the appendices for rules of thumb.)

Under no circumstances should emergency surgery or other necessary medical procedures be delayed because of contaminated skin or wounds. Staff will be protected from becoming contaminated by using universal precautions. Sheets and dressings will keep contamination in place. When the patient is ready to be moved from the ED to other areas of the hospital, the patient can be transferred to a clean gurney. The gurney can be rolled into the potentially contaminated treatment room on a clean sheet. After the patient is transferred onto the gurney he or she can be transported throughout the hospital without concern for the spread of radioactive contamination. Staff can assist in maintaining contamination control by following the standard practices used daily to prevent the spread of disease and infection:

- Follow universal precautions appropriate for the medical condition and type of care being provided to the patient (e.g., gloves, aprons, eye/face protection, shoe covers, etc.).
- Wear masks or face shields if there is a splash hazard and to prevent inadvertent touching of the face.
- Change gloves frequently and between patients.
- Change shoe covers and aprons when moving between treatment areas.
- Survey staff as they transition out of contaminated areas of the ED.
- Wash hands, arms, and any other areas that may have been exposed while working.
- Bag and leave all clothes and shoes worn in the ED to be surveyed before release.
- Consider obtaining a bioassay 24 h after treating patients. Depending on the radionuclides present on the patients, either a 24-h urine sample for LSC analysis or a thyroid bioassay can be performed by radiation safety personnel.

Table 25.5. Substances suitable for decorporation treatment.

Medication	Radionuclide	Dosage schedule in adults	Principle of action
DTPA (diethylene triaminepentaacetic acid, Ca or Zn)	Am, Cf, Co, Cm, Pu, Y	Injection: 1 g/d Infusion: 1 g in 250 mL 5% glucose	Chelation
KI (potassium iodide)	I	130 mg d^{-1} oral[a]	Blocking
Prussian Blue	Cs, Rb, Tl	1–3 g d^{-1} oral	Adsorption
Penicillamine	Heavy metals	300–900 mg every 8 h oral	Chelation
A) Al phosphates B) Alginates C) NH_4Cl	Sr	A) 100 mL gel (13 g) oral B) 10 g oral then 4 g d^{-1} C) 1–2 g every 6 h oral	Adsorption/demin-eralizing

[a]Adult dose. See Table 25.6 for additional information.

Assessment and Therapy for Internal Contamination

Deposition of radioactive materials in the body (i.e., internal contamination) is a time-dependent, physiological phenomenon related to both the physical and chemical natures of the contaminant. The rate of radionuclide incorporation into organs can be quite rapid. Thus, time can be critical and treatment (decorporation) urgent, if an initial survey of the body and nasal swabs indicate possible intakes well above the annual limit of intake for workers of the suspected or known radionuclide(s). If internal contamination is suspected, immediately take nasal swipes (Berger et al. 2003) and plan for 24-h urine and fecal collections (Table 25.4). Several methods of preventing incorporation (e.g., catharsis, gastric lavage) might be applicable, depending on the type of radioactive material present, and can be prescribed by a physician. The Radiation Emergency Assistance Center/ Training Site (REAC/TS 2002) has medical experts on call 24 h a day to provide assistance with issues such as decorporation and treatment of exposed individuals. Some of the medications or preparations used in decorporation (Ca-DTPA, Zn-DTPA, Prussian Blue, etc.) might not be available locally and should be identified and stocked as part of the hospital's radiological emergency medical response plan (Table 25.5). NCRP Report No. 65, "Management of Persons Accidentally Contaminated with Radionuclides," (NCRP 1979) addresses the strategies to limit the exposure from internal contamination by radioactive materials. *Radiation Protection Dosimetry* published a *Guidebook for the Treatment of Accidental Internal Radionuclide Contamination of Workers* (Gerber and Thomas 1992) that provides additional information on patient management, as does *Medical Management of Radiological Casualties* (AFRRI 1999) put out by the Armed Forces Radiobiology Research Institute. In January 2003, the Food and Drug Administration stated that it had determined that Prussian Blue had been shown to be safe and effective in treating people exposed to radioactive elements such as ^{137}Cs or thallium (http://www.fda.gov/cder/drug/infopage/prussian_blue/default.htm). They also stated that Ca-DTPA and Zn-DTPA are safe and effective for treatment of internally deposited Pu, Am, and Cm (http://www.fda.gov/bbs/topics/NEWS/2003/NEW00950.html). In addition, if it is suspected that the patient

Table 25.6. Threshold thyroid radioactive exposures and recommended doses of KI for different risk groups.

Risk group	Predicted thyroid exposure (cGy)	KI dose (mg)	No. of 130-mg tablets	No. of 65-mg tablets
Adults over 40 y	≥ 500	130	1	2
Adults over 18–40 y	≥ 10	130	1	2
Pregnant or lactating women	≥ 5	130	1	2
Adolescents over 12–18 y[a]	≥ 5	65	1/2	1
Children over 3–12 y	≥ 5	65	1/2	1
Children over 1 mo–3 y	≥ 5	32	1/4	1/2
Birth–1 mo	≥ 5	16	1/8	1/4

[a]Adolescents approaching adult size (≥ 70 kg) should receive the full adult dose (130 mg). Saturated Solution of potassium iodide (SSKI) can be used in place of tablets. SSKI contains 1g of KI mL^{-1} of solution. 130 mg of SSKI = 0.13 mL, or approximately three drops. Dilute in juice. From: Guidance: Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies. U.S. Department of Health and Human Services, Food and Drug Administration, December 2001.

may have been exposed to volatile iodine, the FDA (http://www.fda.gov/cder/guidance/4825fnl.htm) and the National Academies (http://books.nap.edu/catalog/10868.html) have published guidelines for administration of potassium iodide (KI), a blocking agent, to help protect the thyroid gland (Table 25.6).

Acute Radiation Syndrome in Accident Victims

Radiation sickness (acute radiation syndrome [ARS]) is rare but may present as an acute illness in patients following exposure to very large doses of ionizing radiation. ARS does not occur in staff treating patients who have been exposed to radiation or are contaminated with radioactive material. ARS in patients follows a roughly predictable course over a period of time ranging from a few hours to several weeks. The severity of the symptoms increases with radiation dose, amount of the body exposed (whole-body vs. partial-body exposure), and the penetrating ability of the radiation. The severity is also affected by factors such as age, gender, genetics, medical conditions, etc. The signs and symptoms that develop in ARS occur in four distinct phases: prodromal (initial), latent period, manifest illness stage, and recovery or death. Due to the timing of victims being seen in the ED after a terrorist attack, it is likely that only the prodromal phase would be encountered. Depending on the dose of radiation, patients may experience a variety of symptoms including loss of appetite, nausea, vomiting, fatigue, and diarrhea. Severity and time of onset of these symptoms should be noted and treated in a routine clinical manner. The higher the radiation dose to the victim, the more severe and rapid the onset of signs and symptoms. It should be emphasized that the probability of seeing a patient exposed to such a high radiation dose is very unlikely.

If it is believed that the victim received a high radiation dose, complete blood cell with absolute lymphocyte count should be taken initially and about every 6 h thereafter (purple top tube containing EDTA). The higher the radiation dose to the patient, the more severe the drop in the concentration of circulating lymphocytes and other blood elements. The concentration of lymphocytes in circulation can be altered by trauma, which can complicate the use of this as an indicator for radiation exposure. If chromosomal analyses are ordered, dark green top tubes (sodium heparin tube) should be used to collect the blood samples; light green top tubes (lithium heparin with gel) are not acceptable. Treatment should focus on prevention of infection. Antibiotics should be given to sterilize the gut and treat opportunistic infections. Hematopoietic growth factors should be given within the first 24 to 48 h and then daily. Patients with higher exposures will require hospitalization.

Partial body radiation can cause localized effects if the dose is sufficiently high. The patient may not be aware that he or she was exposed. Such a patient may have localized, burnlike skin injuries without a history of heat exposure. These symptoms do not appear immediately, but rather days after exposure. Epilation, a tendency to bleed, nausea, and vomiting and/or other symptoms of the ARS may be present. If a patient presents with burns immediately after a terrorist event, such as a dirty bomb, the chances are good that the burns are thermal burns, not radiation burns.

Patients who have suffered trauma (from an explosive or burn) combined with an acute, high-level exposure to penetrating radiation will have increased morbidity compared to patients who have received the same dose of radiation without trauma. If a patient has received an acute dose greater than 100 rad, efforts must be made to close wounds, cover burns, reduce fractures, and perform surgical stabilizing and definitive treatments within the first 48 h after injury. After 48 h, surgical interventions should be delayed until hematopoietic recovery has occurred.

Health Effects of Radiation Exposure

There are several sets of recommendations for acceptable radiation dose limits to emergency workers performing life-saving actions. The Nuclear Regulatory Commission recommends 25 rem (USNRC 2003), while the NCRP (NCRP 1991) and International Council on Radiation Protection (ICRP 1990) recommend that doses can approach or exceed 50 rem for life-saving activities. While these doses are 5 to 10 times higher than annual occupational dose limits, they represent a modest increase in cancer risk during life-saving measures. It should be noted that emergency workers should perform these life-saving activities voluntarily and with prior training regarding the risks of exposure. This emphasizes the importance of utilizing the training module described earlier as part of the routine training for ED staff. One of the most important points to stress when training emergency responders is that radiation is a weak carcinogen. At doses below 10 rem, the potential for cancer causation is uncertain and generally believed to be quite small (http://hps.org/documents/radiationrisk.pdf). At doses likely to be received in the ED (< 5 rem), the increased risk of cancer is minimal.

Concern over radiation-induced hereditary (genetic) effects is quite common due to a century of misrepresentation, by the media and the entertainment industry, of radiation's ability to produce such effects. No direct evidence of hereditary effects exceeding normal incidence have been observed in any of the studies of humans exposed to radiation, even after high doses of radiation (UNSCEAR 2001). The natural incidence of malformations and genetic disease at 1 to 2 yr of age is 6 to 10% (Mossman and Hill 1982). Using a theoretical model, the increased risk of genetic effects to children of young emergency responders would be ~ 0.02% from 5 rem and ~ 0.2% from 50 rem. Although it would be quite rare for someone providing care for a radioactively contaminated patient to exceed 5 rem, it is prudent to exclude pregnant staff from such cases whenever possible. In general, fetal doses would have to be considerably higher than 5 rem before abortion were considered and, then, only on advice from a physician with appropriate expertise on radiation and pregnancy.

Facility Recovery

If the efforts put forward during facility preparation were successful, facility recovery should be relatively easy. Once again, emphasis on maintaining exposures ALARA should be stressed.

If an in-house radiation safety staff is available, they will supervise decontamination efforts. Waste from the ED and triage area should be taken to a designated holding location until it can be surveyed for radioactive material prior to disposal. Some facilities have radiation monitors to survey hospital trash. This is a quick method that can replace hand surveying of each bag of waste. A radiation survey of the facility will identify any surfaces that require decontamination. Normal cleaning routines are typically very effective. Facilities should be decontaminated to the extent possible. Gloves, shoe covers, and coveralls should be worn by individuals decontaminating the radiation emergency area. For some contaminated items, replacement may be more cost-effective and practical than decontamination. If there is residual contamination after normal cleaning, items such as furniture and floor tiles can be replaced. The decontamination goal for surfaces is to have less than twice the normal background reading. Levels that cannot be decontaminated to this level should be referred to the health physics staff.

There are many resources available, including books, journal articles and Internet sites, that will be useful in preparing a hospital emergency plan tailored to suit the needs of different organizations. Following are some examples:

- Organizations

  Radiation Emergency Assistance Center/ Training Site (REAC/TS); (865) 576-1005; www.orau.gov/reacts

  Medical Radiobiology Advisory Team (MRAT) Armed Forces Radiobiology Research Institute (AFRRI); (301) 295-0530; www.afrri.usuhs.mil

Centers for Disease Control and Prevention (CDC); (888) 246-2675; www.bt.cdc.gov/radation/links.asp

- Books and Reports

  Medical Management of Radiation Accidents; Gusev, Guskova, and Mettler, 2001.
  Medical Effects of Ionizing Radiation; Mettler and Upton, 1995.
  The Medical Basis for Radiation-Accident Preparedness; REAC/TS Conference, 2002
  National Council on Radiation Protection Reports Nos. 65 and 138
  Disaster Preparedness for Radiology Professionals, www.acr.org
  Medical Management of Radiological Casualties Handbook and Terrorism with Ionizing Radiation Pocket Guide; Jarrett, 2003.

- Article

  "Major radiation exposure: What to expect and how to respond," Mettler and Voelz, N Engl J Med 346:1554–1561, 2002.

- Online

  "Emergency Department Management of Radiation Casualties"; Bushberg et al., http://hps.org/hsc/emergency.ppt, 2003.

Summary

Medical stabilization and treatment of the patient takes priority over decontamination efforts. Radiation exposure and contamination from victims of an RDD are not a significant hazard to personnel. The staff can protect themselves from radioactive contamination by using universal precautions while treating these patients. As opposed to patients who arrive contaminated with certain chemical or biological agents, radioactive contamination is easy to measure and is unlikely to cause adverse effects to medical personnel. Every emergency department should have a medical radiation emergency plan that will allow effective and efficient handling of potentially contaminated and injured patients. Planning and preparation for radiation casualties should be incorporated into the hospital's emergency preparedness program to ensure successful response to incidents involving radiation. When such a plan exists and is tested through periodic drills, it minimizes the potential for apprehension and panic should activation of the plan ever be needed. The plan should address patient assessment and management of radioactive contamination and radiation injuries. Training should emphasize that resuscitation and stabilization are the most important aspects of treating the radiation accident victim(s). Remembering the essentials of first response (i.e., treat the patient, not the poison) is critical to appropriate treatment of injuries associated with radiation exposure and contamination.

Preplanning will ensure that adequate supplies and survey instruments are available. Non-ED staff that can assist in a radiological emergency situation should be identified and trained in advance. Staff from nuclear medicine, radiation oncology, and radiation safety departments have expertise in radiation protection practices and the use of survey meters.

Most victims of a RDD will arrive at the ED with a minimal amount of contamination. ED staff are likely to receive far less than the standard occupational exposure limit of 5 rem. It is important to emphasize during training that even in an extreme case involving radiation casualties, such as that which occurred at the Chernobyl site after the accident in 1986, medical personnel working on the victims received less than 1 rem. (Mettler and Voelz 2002). In the case of a RDD, exceptional dose rates could exist if embedded shrapnel from the RDD was intensely radioactive. This remote possibility would be easy to determine with appropriate radiation survey equipment.

It is important for ED staff to recognize that most victims of radiation accidents will show no signs or symptoms at all due to the low level of their exposure. In the rare instance when an event involves high levels of radiation exposure, early symptoms and their intensity in the patient will be an indication of the severity of the radiation injury. In either circumstance, treating these patients is not an immediate health hazard to ED staff and the long-term risks from radiation exposures of less than 5 rem are very small.

It is important to keep in mind that the first 24 h after an incident occurs will be the most challenging for the emergency responder. After the first day, there will likely be many additional resources arriving from state and federal agencies. Understanding the basic science of radiation protection will aid the care providers in effectively and efficiently managing these patients.

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References

AFRRI. Medical management of radiological casualties. McLean, VA: International Medical Publishing; Armed Forces Radiobiology Research Institute; 2003.

Berger ME, Jones OW, Ricks RC, Garrett S. Decontaminating the nasal passages. Operational Rad Safety, Suppl. to Health Phys 84:S80–S82; 2003.

Centers for Disease Control and Prevention. Department of Health and Human Services, Interim guidelines for hospital response to mass casualties from a radiological incident. Available at: www.bt.cdc.gov/radiation/pdf/masscasualties.pdf.

DeMuth WE, Miller KL. Disaster planning for mass casualties. In: Early care of the injured patient. 3rd ed. Philadelphia: W.B. Saunders; 1982: 376–384.

Donovan JW, Trautlein JJ, Miller KL, Muller HA. Disaster management during a nuclear accident. Disast Med 1:405–407; 1983.

Gerber GB, Thomas RG, eds. Guidebook for the treatment of accidental internal radionuclide contamination of workers. Radiat Prot Dosim 41:5–49, 1992.

International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection. New York: Elsevier Science; ICRP Publication 60, Annals of the ICRP 21; 1990.

Mettler FA. Hospital preparation for radiation accidents. In: Gusev IA, Guskova AK, Mettler FA, eds. Medical management of radiation accidents, 2nd ed. Boca Raton, FL: CRC Press; 2001: 425–435.

Mettler FA, Voelz GL. Major radiation exposure: what to expect and how to respond. N Engl J Med 346:1554–1561; 2002.

Miller KL. Techniques and methods of disseminating information to the public about radiation and nuclear power. In: Miller KL, Weidner WA, eds. Handbook of management of radiation protection programs. Boca Raton, FL: CRC Press; 1986: 35–37.

Miller KL. The nuclear reactor accident at Three Mile Island. Radiographics 14:215–224; 1994.

Miller KL. The regional approach to management of radiation accident victims. In: Vince MA, ed. Coping with radiation accidents. Ravenna, OH: Envirotox Management, Inc.; 1990: 121–130.

Miller KL, DeMuth WE. Handling radiation emergencies: no need to fear. J Emerg Nurs 9:3141–3144; 1983.

Miller KL, Weidner WA. Medical center preparations for Three Mile Island. In: Brodsky A, ed. Handbook of radiation measurement and protection, Vol. II, Section A. Boca Raton, FL: CRC Press; 1982: 699–708.

Mossman KL, Hill LT. Radiation risks in pregnancy. Obstet Gynecol 60:237–242; 1982.

National Council on Radiation Protection and Measurements. Developing radiation emergency plans for academic, medical or industrial facilities. Bethesda, MD: NCRP Publications; NCRP Report No. 111; 1991.

National Council on Radiation Protection and Measurements. Management of persons accidentally contaminated with radionuclides. Bethesda, MD: NCRP Publications; NCRP Report No. 65; 1979.

National Council on Radiation Protection and Measurements. Management of terrorist events involving radioactive materials. Bethesda, MD: NCRP Publications; NCRP Report No. 138; 2001.

Radiation Emergency Assistance Center/ Training Site (REAC/TS). Phone: (865) 576-1005; URL: www.orau.gov/reacts/ ; 2002.

Toohey RE. Role of the health physicist in dose assessment. In: Ricks RC, Berger ME, O'Hara FM, Jr., eds. Medical basis for radiation-accident preparedness, New York: Parthenon Publishing Group; 2002: 33–43.

United Nations Scientific Committee on the Effects of Atomic Radiation. Hereditary effects of radiation. New York: United Nations; Report to the General Assembly, with scientific annexes; No. E.01.1X.2; 2001.

U.S. Nuclear Regulatory Commission. Standards for protection against radiation. Washington, D.C.: U.S. Government Printing Office; 10 CFR20; 2003.

Weidner WA, Miller KL, Rohrer GV, Latshaw RF. The impact of a nuclear crisis on a radiology department. Radiology 135:717–723; 1980.