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Selected Topics: Disaster Medicine

NUCLEAR/RADIOLOGICAL TERRORISM: EMERGENCY DEPARTMENT MANAGEMENT OF RADIATION CASUALTIES

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☐ **Abstract—Recent world events have increased concern that hospitals must be prepared for radiological emergencies. Emergency departments (EDs) must be ready to treat patients suffering from injuries in combination with radiation exposure or contamination with radioactive material. Every hospital should have a Radiological Emergency Medical Response Plan, tested through periodic drills, which will allow effective handling of contaminated and injured patients. Treatment of life-threatening or severe traumatic injuries must take priority over radiation-related issues. The risk to ED staff from radioactive contamination is minimal if universal precautions are used. The likelihood of significant radiation exposure to staff under most circumstances is small. Educating medical staff on the magnitude of the radiological hazards allows them to promptly and confidently provide the necessary patient care. Measures must be taken to prevent the "worried well" and uninjured people with radioactive contamination from overwhelming the ED. © 2007 Elsevier Inc.**

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INTRODUCTION

The concern that emergency department (ED) personnel will have to care for patients injured or contaminated by a terrorist act involving radioactive material has increased dramatically since the end of the cold war in the early 1990s. Sealed sources containing large amounts of radioactive material suitable for use by a terrorist are widely used in medicine and industry, and many large sealed sources have been lost from governmental oversight, particularly in developing countries and states that were part of the former Soviet Union (1). This article is intended to assist hospitals and emergency departments in preparing for nuclear/radiological terrorism and for accidents involving radiation injuries or radioactive contamination.

There are many possible terrorist radiation injury scenarios, including: 1) covert placement of a sealed radioactive source in a public location, 2) the use of a radiological dispersal device (RDD), 3) an attack on or sabotage of a nuclear facility, and 4) detonation of a nuclear weapon (atomic bomb), which is a remote but possible threat (1,2). A sealed source may be covertly placed in a location that would expose many people until the presence of the source is discovered. Although many people could be exposed, it is unlikely that any would be contaminated. An RDD is not a nuclear weapon; instead, it is a device designed to spread radioactive material for the purpose of terrorism. An RDD that uses a conven-

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tional explosive (e.g., dynamite or a plastic explosive) to spread the radioactive material is called a "dirty bomb." Although 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 limited dispersion by such an explosion, it is unlikely that the exposure or contamination of people outside the immediate blast area will have any clinical effect beyond the psychological impact from the fear of radiation and perhaps a slightly increased risk of cancer. To date, there has been no use of an RDD; however, the materials to produce an RDD have been intercepted by law enforcement (3).

An attack on or sabotage of a nuclear facility, such as a commercial irradiation facility or a nuclear power plant, could release large amounts of radioactive material. Detonation of a nuclear weapon (even one with a relatively low energy yield) in a populated area would result in extensive loss of life and widespread contamination. The use of a stolen or improvised nuclear device is the least likely scenario, due to the strict security controls over nuclear weapons and weapons-grade plutonium and uranium and the technical difficulty of constructing such a weapon, but the potential number of injured people is many times greater than from the other scenarios. In the case of a nuclear weapon detonation or an event resulting in the dispersion of used nuclear reactor fuel, the radioactive contamination will consist of many radionuclides, including radioactive isotopes of iodine.

In all scenarios involving the release of radioactive material, radioactive contamination would be present at the site of the event. There may also be deposition of radioactive material by a downwind plume. The amount of contamination deposited by the plume would depend upon the nature of the event, the amount of radioactive material released, and atmospheric conditions such as wind speed.

There are several scenarios, other than those caused by terrorism, in which radiation 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. The Radiation Emergency Assistance Center Training Site (REAC/TS) recorded 428 major radiation accidents worldwide between 1944 and 2005, resulting in 126 radiation-related deaths (4). Although these accidents were infrequent, heightened awareness of the potential impact from terrorist activity has prompted many hospitals to reassess their preparedness for radiological emergencies.

IONIZING RADIATION AND RADIOACTIVE MATERIAL DEFINITIONS

Ionizing Radiation

Ionizing radiation, such as X- and gamma rays as well as alpha and beta particles, has the ability to ionize matter, causing chemical changes that can modify DNA and kill cells. Throughout this article, the term *radiation* will refer only to ionizing radiation. Radiation is a natural part of the environment. People are constantly exposed to radiation from their surroundings, (e.g., the earth itself, building materials, air, and water) as well as from cosmic rays. On average, persons in the United States receive about 300 millirem (mrem) of radiation per year from natural sources (5). People are also exposed to manmade radiation from medical imaging (e.g., radiology and nuclear medicine studies), medical therapy (e.g., cancer treatment), industry (e.g., soil moisture density gauges and nuclear power plants), and research.

Radioactive Material

Radioactive material consists of atoms with unstable nuclei. The traditional unit of activity is the curie, defined in Table 1. Contamination of people usually involves microcurie (μCi; one millionth of a curie) to millicurie (mCi; one thousandth of a curie) quantities. Nuclear Medicine patients are injected with μCi to mCi quantities of short-lived radioactive material for routine diagnostic examinations. The amount of radioactivity continuously decreases with time, a phenomenon referred to as radioactive decay. The physical half-life is the time required for radioactive material to be reduced to half the initial amount by radioactive decay. The effective half-life combines the physical half-life with biological elimination (e.g., urination, defecation, exhalation, and sweating). Most of the radionuclides that are considered likely to be used in an RDD (see below) have physical half-lives of 5 years or more.

Two common types of radioactive decay are alpha particle emission and beta particle emission. Alpha particles travel very short distances (< 0.1 mm) and therefore, are only harmful when alpha-emitting radionuclides are inhaled, swallowed, or present in a wound. Some beta particles can travel up to 10 meters or more in air and a centimeter or more in soft tissue. Thus, most beta-emitting radioactive materials, if allowed to remain on the skin for a prolonged period of time, can cause skin injury. Beta-emitting contaminants may also be harmful if deposited internally. Gamma radiation and X-rays are also emitted by many radioactive materials and travel many meters in air and many centimeters in living tissue.

Table 1. Radiation Units

Quantity	Definition	Traditional Unit	SI Unit*	Unit Conversion
Activity	Amount of radioactivity; number of atoms undergoing nuclear transformations (nt) per time	curie (Ci) 1 Ci = 37×10^9 nt/s	becquerel (Bq) 1 Bq = 1 nt/s	1 Ci = 37×10^9 Bq
Absorbed dose	Energy imparted per mass	rad 1 rad = 0.01 J/kg	gray (Gy) 1 Gy = 1 J/kg	100 rad =1 Gy
Effective dose	Sum of absorbed doses to organs, each multiplied by a tissue weighting factor	rem	sievert (Sv)	100 rem = 1 Sv
Exposure	Ionization in air per mass air	roentgen (R)	coulomb/kilogram (C/kg)	1 R = 2.58×10^{-4} C/kg

* Although international units (SI) are used by professionals in radiation protection, most instruments and many labels on sources of radioactive material still use traditional units.
For X- and gamma radiation, 1R ≅ 1 rad ≅ 1 rem.

Layers of dense materials, such as lead, are commonly used to shield against gamma radiation and X-rays. Some of the radioactive materials considered likely to be used in an RDD are the beta emitters cesium-137 (Cs-137), cobalt-60 (Co-60), iridium-192 (Ir-192), strontium-90 (Sr-90), and iodine-131 (I-131), and the alpha emitters americium-241 (Am-241), californium-252 (Cf-252), and plutonium (Pu) (1,6).

Quantities and Units for Describing Ionizing Radiation

The amount and rate of energy deposition in tissue by radiation are major determinants of biological effects. *Absorbed dose*, commonly referred to as *dose*, is defined as the amount of energy deposited per unit mass of matter. The traditional unit of dose is the rad (Table 1).

The biological effects of radiation also depend on the type of radiation. Some types of radiation, such as alpha particles and neutrons, are more biologically damaging per unit dose than X- and gamma rays. The *effective dose* reflects the biological damage per unit dose (Table 1). The traditional unit of effective dose is the rem. For practical purposes when dealing with beta, gamma, and X radiation, 1 rad = 1 rem.

Contamination vs. Exposure

The difference between radioactive contamination and radiation exposure is important to understand. Radioactive contamination is radioactive material that is in an unwanted location. In the case of an accident victim, it may be on the skin or clothes of the person or have entered the body by inhalation, ingestion, or through a wound. Contaminated patients require careful handling to effectively remove and limit the spread of contamination. Patients are not contaminated if they have only been exposed to ionizing radiation from a radioactive source or an X-ray machine. They do not pose any hazard to hospital personnel and radiation safety precautions are not needed.

EMERGENCY DEPARTMENT AND HOSPITAL PROCEDURES

Protection of Staff

Reducing exposure. The three methods for reducing radiation exposure from a source external to the body to levels that are as low as reasonably achievable (ALARA) are time, distance, and shielding. Radiation exposure rates decrease greatly (by the square of the distance) as you increase the distance from the source. For example, doubling the distance from the source decreases the radiation exposure rate to one-quarter. The time spent in close proximity to the severely contaminated patient should be kept to a minimum while providing the necessary medical care. In general, exposure from contaminated patients will be minimal and, in most cases, lead aprons are not recommended.

Protection from contamination. Hospital staff are well versed in protecting themselves and their work areas from biological contamination through the use of "Universal Precautions." The same precautions can be used effectively to protect personnel and the work area from contamination by radioactive materials. The only variation from normal universal precautions is a recommendation to wear two sets of gloves and to change the outer pair as needed to avoid cross-contamination. It should be pointed out that in the case of a multi-hazard incident

Figure 1. A GM survey meter (below) will detect small amounts of radioactive contamination. It is useful in locating contamination and assessing the effectiveness of decontamination efforts. An ion chamber survey meter (above) will measure the exposure rate from X- and gamma radiation.

(e.g., radioactive materials and chemicals), higher levels of personal protective equipment may be necessary.

Detection and measurement of radiation. Hospitals with Nuclear Medicine or Radiation Oncology departments have radiation monitoring instruments. The ED should either have its own or ready access to such instruments that are properly maintained and calibrated. The ED training program should include instruction on instrument operation including the proper means of determining the background levels. Background readings should be taken in an area of the ED remote from the areas that may be contaminated. The most commonly used instruments to detect the presence of radioactive material and radiation are the Geiger-Mueller (GM) survey meter (also known as a Geiger counter) and the ionization chamber survey meter (Figure 1). The GM survey meter will detect small amounts of radioactive contamination and typically has the capability of distinguishing between alpha, beta, and gamma radiation. It is used to quickly determine if a person is contaminated and where the contamination is located. Ionization chamber survey meters are used to measure exposure rates from low (mR/hr) to high (R/hr) levels of radiation. To determine the exposure a person actually receives, the measured exposure rate must be multiplied by the time that the person was exposed. For example, if staff were caring for a contaminated patient for 15 min and the ionization chamber reading was 5 mR/hr, the staff would be exposed to 1.25 mR, less than the radiation exposure received from cosmic radiation during a cross-country airplane flight (approximately 2.5 mrem). The average natural radiation dose to people living in the United States is 300 mrem per year. Other specialized equipment, such as multi-channel analyzers (MCA) that allow radionuclide identification, might only be available if the hospital has health physics or medical physics staff.

A personal dosimeter is a device that measures the dose of radiation received by the person wearing it. Film badge dosimeters must be sent for analysis so the radiation dose received is not known for several days. Self-reading dosimeters, although not as accurate as film badges, allow the wearer to see the total radiation dose they have received at any time. Some of these are equipped with alarms that alert the wearer when a set point is exceeded. Ideally, both types of dosimeters should be used by staff working directly with contaminated patients.

Hospital Plan

The hospital should have a well-thought-out Radiological Emergency Medical Response Plan and should test it periodically by drills. This may be part of the emergency management plan required by the Joint Commission on Accreditation of Hospital Organizations (JCAHO) (7). There are several excellent documents that can assist in plan development (2,8–13). The plan should ensure that the medical care of the patient takes priority over decontamination. Resuscitation and stabilization are the primary objectives, with decontamination efforts being secondary. The plan should address contamination control for staff and facilities, including control and survey of materials and personnel entering and leaving the contaminated area (Table 2). Facility preparation depends on the time available until patient arrival as well as the number of patients expected. In situations involving other types of hazardous materials, such as chemicals, decontamination of the victims typically occurs before transportation to the ED. Although this approach may be appropriate for some chemical and biological agents, it is unnecessarily restrictive for radiological contamination, which poses very little risk of harm to the emergency responders. In addition, many casualties will likely self-refer to the nearest hospital and therefore not be decontaminated. The hospital plan should specifically address the issue and provide for admission of critical patients directly into the ED or related services (e.g., CT, surgery) without decontamination if a delay would be life threatening. Emergency medical technicians should attempt to decon-

Table 2. Facility Management of Radiological Emergencies

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.
Protect staff from contamination
Use universal precautions and double glove.
Survey hands and clothing with radiation survey meter.
Replace gloves and gowns if contaminated and between patients.
Keep areas outside the treatment area free from contamination.
Control contamination
Instruct staff to use universal precautions.
Provide multiple containers for contaminated waste.
Protect the floor with covering if time permits.

taminate the victims in the field if the patients are stable, remembering that medical management is the first priority. Typically, 90% of radioactive contamination is removed when the clothes are removed (14). What little remains will likely stay in place if the patient is wrapped in a sheet and transported.

There should be a call list to notify the staff on duty, as well as to obtain additional staff and equipment that will be needed. The additional support for the ED could come from hospital staff in Nuclear Medicine, Radiation Oncology, Diagnostic Radiology, and Radiation Safety/Health Physics. If radiation safety personnel are available, they will be a valuable asset in the management of the flow of people through the ED. They can perform surveys of the accident victims, assist in contamination control, and provide radiation dose assessment (15). The plan should address where to obtain radiation survey meters. Diligent use of survey meters by staff (e.g., survey gloves and change as necessary, survey shoes when leaving, etc.) will help prevent the spread of contamination (Figure 1).

The plan should designate a triage area outside the ED. In this area, assessment can be made as to whether or not a person needs to be seen in the ED (2,16). A mass casualty incident involving radioactive material is likely to generate large numbers of frightened people who do not require acute medical care (2,14). The plan should provide for centers for assessment of minor injuries, decontamination, and counseling of these persons away from the ED so that the ED is not inundated. These centers should be staffed by physicians with radiological training, health physicists or other staff trained to use radiation survey instruments, and psychological counselors. The hospital should also plan to provide psychological support to patients and hospital staff.

Patient flow in the ED should be established in a manner that will control the spread of contamination (Figure 2) (9,16,17). Several methods to consider are: placing a floor covering on one side of the hallway from the ED entrance to the treatment room; designating a separate entrance for contaminated patients; and transferring the contaminated patient to a clean gurney before entering the ED. Ideally, the treatment room floor should be covered, but only if time allows for such an activity. Containers for waste should be set up to limit the spread of contamination. Compared to chemical and biological hazards, one advantage of radioactive contamination is the ease with which it can be detected. Frequent use of the GM survey meter can alert personnel of the need to change their gloves or clothing when they become contaminated and to identify when contamination is being spread so that cleanup and extra precautions can be implemented. Contamination in the ED may occur, but this should not preclude the continued use of the treatment areas or equipment during the event.

The plan should identify a laboratory that can assay samples collected to assess external and internal contamination (Table 3). The laboratory should be capable of identifying the radionuclide(s) involved and estimating the amounts of radioactive material in the samples, particularly in regards to possible internal contamination (discussed below under "Assessment and Therapy for Internal Contamination"). A gamma-ray spectroscopy system with an MCA is particularly useful for identifying radionuclides. A medical center with full time radiation safety staff will likely have this capability and a Nuclear Medicine department can develop this capability. Arrangements should be made in advance so that the laboratory can calibrate its equipment for the radionuclides likely to be encountered and provide staff training.

PATIENT ASSESSMENT AND MANAGEMENT OF RADIOACTIVE MATERIAL CONTAMINATION AND RADIATION INJURIES

Patient Assessment

Questions about the circumstances surrounding the incident as well as a GM survey of the patient will provide valuable patient management information and will further assist in predicting the extent of radiation injury (9,13,18). Although contamination surveys are secondary to patient stabilization, they should be conducted as soon as possible. In the case of an RDD, very high dose rates could exist if embedded shrapnel from the RDD is intensely radioactive, which is easily determined with radiation survey equipment. This type of shrapnel should be transferred to lead containers (readily available from Nuclear Medicine departments and commonly referred

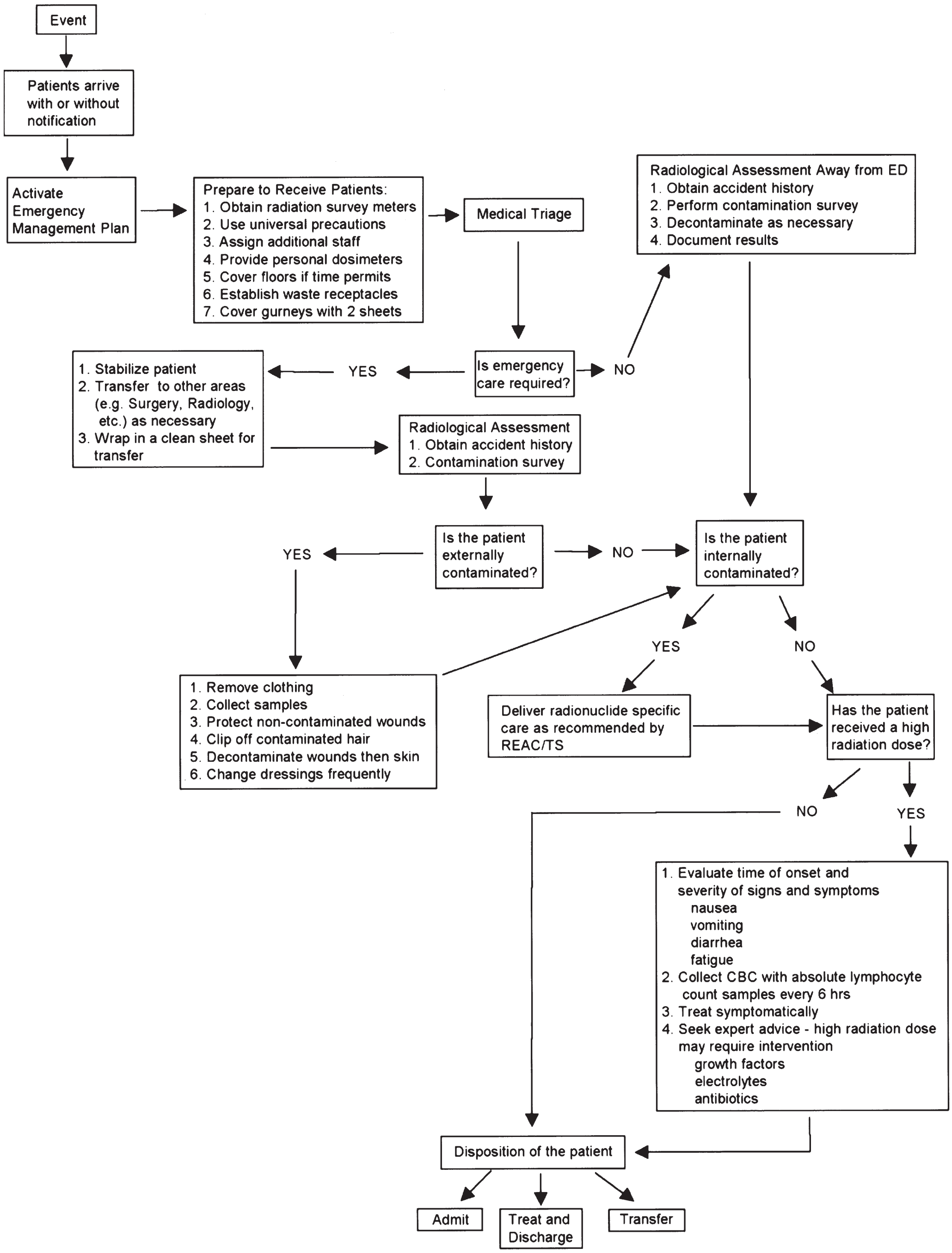

Figure 2. Patient flow through the ED. Familiarization of the ED staff to the hospital's Emergency Management Plan through the use of periodic drills will maximize their effectiveness and allow for optimal care of the patients being seen.

to as "pigs") and placed distant from staff. Specimens collected for medical assessment can yield valuable information for treatment planning (Table 3). Samples collected to assess contamination should be placed in containers and labeled with the patient's name, date, time of collection, and sample location. ED staff should be aware that elevated radiation measurements from a patient may be caused by radioactive material from a recent nuclear medicine or radiation oncology procedure instead of radioactive contamination from an event. Nausea and vomiting are signs of exposure to a high radiation dose (see Acute Radiation Syndrome section below), but such a dose from terrorist activities is unlikely. Consequently, if such symptoms are present, they may be psychological in nature.

Table 3. 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 Suspected 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 and assess change over time. A significant decrease in lymphocyte count is an early predictor of radiation dose. See Table 7	Veni-puncture in uncontaminated skin area into purple top tube containing EDTA; cover puncture site.
Blood: Chromosomal analysis	Chromosomal analyses are the most accurate way of estimating the radiation dose. Specialized labs are required and results take several days. See Table 7	Veni-puncture in uncontaminated skin area into lithium heparin tube; if that is not available, use an EDTA tube. 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 or liquid scintillation counter, or multichannel analyzer 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. Analyze with GM probe, gamma or liquid scintillation counter, or multichannel analyzer if available.	Assess if 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 from the wound or skin, transfer it to lead containers (pigs).
When Internal Contamination is Suspected		
Urine bioassay: 24-h specimen; repeat for 4 days	Body excreta may contain radionuclides if internal contamination has occurred.	Use standard specimen containers.
Feces bioassay: 24-h specimen; repeat for 4 days		

Adapted from Radiation Emergency Assistance Center/Training Site (REAC/TS) (4): Hospital emergency care of the radiation accident patient, 2002, http://www.orau.gov/reacts/emergency.htm.

Decontamination

Decontamination should not delay or impede stabilization of the patient (Table 4). Removal of clothing generally reduces contamination on the patient by 90% (14). Usual washing methods are effective for removal of radioactive contamination. Non-contaminated wounds should be protected with waterproof dressings to minimize uptake of radioactive material during decontamination efforts. 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. Decontamination efforts should not cause the skin to become abraded. Openings in the skin allow increased absorption of radioactive material. If an area of contaminated skin persists, cover the area with gauze and a glove or plastic to promote sweating, which can remove radioactive material from pores. Remove contaminated hair, if necessary, using scissors or electric clippers. To avoid cutting the skin, do not shave.

To decontaminate wounds, irrigate with tepid water and gently wash with soap and a surgical sponge or gauze pad. Normal wound debridement can be performed. Excision around wounds solely to remove contamination should be performed only in extreme cases and upon the advice of radiological emergency medical experts. Contaminated thermal burns can be gently rinsed, but should not be scrubbed, to prevent further damage to the skin. 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. Cease decontamination of the skin and wounds when the area is less than twice the background reading on the GM survey meter or if there is no significant reduction between washes.

Under no circumstances should emergency surgery or other necessary medical procedures be delayed due to 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 clean gurney can be brought into the contaminated treatment room by rolling

Table 4. Step-By-Step Patient Decontamination

1. Do not delay surgery or other necessary medical procedures or examinations; residual contamination can be controlled.
2. Carefully remove and bag patient's clothing and personal belongings (typically removes 90% of contamination).
3. Survey patient and, if practical, collect samples.
4. Handle foreign objects with care until proven non-radioactive with a radiation survey meter.
5. Priorities
   A. Decontaminate wounds first then intact skin.
   B. Start with the highest levels of contamination.
   C. Protect non-contaminated wounds with water-proof dressings.
   D. Irrigate and gently scrub contaminated wounds with a surgical sponge.
   E. Extend wound debridement for removal of contamination only in extreme cases and upon expert advice.
   F. Change dressings frequently.
6. Decontaminate thermal burns by gently rinsing. Aggressive washing may increase the severity of injury. Additional contamination will be removed when dressings are changed.
7. Decontaminate intact skin and hair by washing with soap and water.
8. Remove stubborn contamination on hair by cutting with scissors or electric clippers.
9. Promote sweating for residual skin contamination.
10. Avoid overly aggressive decontamination.
11. Cease decontamination of skin and wounds:
    A. When the area is less than twice background, or
    B. When there is no significant reduction between decontamination efforts, and before the skin becomes abraded.
12. Change outer gloves frequently to minimize spread of contamination.
13. Use survey meter to monitor progress of decontamination.

it over clean paper or other clean material placed on the floor. After the patient is transferred onto the gurney, wrap a clean sheet around the patient and he or she can be transported throughout the hospital without spreading radioactive contamination.

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. Internal contamination occurs mainly by inhalation, ingestion, or absorption through wounds, although percutaneous absorption occurs with some radioactive materials. The fraction of the radioactive material that is absorbed into the body depends upon the radionuclide, chemical and physical form, and route into the body. For example, soluble plutonium is readily absorbed into the body through the lungs or a wound, but only very slightly if ingested. Furthermore, the amount of radioactive material that poses a significant threat if taken into the body varies greatly with radionuclide and chemical form. For example, 100 μCi of Cs-137 chloride in the body would not pose a significant threat, but less than 1 μCi of soluble plutonium would. In many cases, early treatment is necessary if it is to have much effect. Thus, time can be critical and treatment decisions may need to be made based on preliminary information. If internal contamination is suspected, plan for 24-h urine and fecal collections (Table 3), but the decision to treat suspected internal contamination should not be delayed until these samples are collected or analyzed (19). If an MCA is available, it will be a valuable tool to expedite the determination of which decorporation therapy is appropriate based on the radionuclide(s) present. Also, if inhalation of radioactive material is suspected, immediately take nasal swabs. A separate swab should be obtained from each nostril and placed in its own container. Radioactivity on both nasal swabs should be considered evidence of inhalation of radioactivity, but lack of radioactivity on the swabs should not lead to the presumption that such material was not inhaled. Several methods of preventing incorporation (e.g., catharsis, gastric lavage) might be applicable, depending on the type of radioactive material present. NCRP (National Council on Radiation Protection) Report No. 65, *Management of Persons Accidentally Contaminated with Radionuclides* (17), the *Guidebook for the Treatment of Accidental Internal Radionuclide Contamination of Workers* (20), and *Guidance for Industry, Internal Radioactive Contamination—Development of Decorporation Agents* (21) provide clinical guidance on the management of internal contamination. The NCRP is currently working on an update to Report No. 65 that will contain additional information. REAC/TS has medical experts on call 24 h a day to provide assistance with issues such as decorporation and treatment of exposed individuals (4). Some of the medications or preparations used in decorporation (trisodium calcium-diethylenetriaminepentaacetate [Ca-DTPA], Zn-DTPA, Prussian Blue, etc.) might not be available locally and should be stocked (or a source identified in the community) as part of the hospital's Radiological Emergency Medical Response Plan (Table 5). The U.S. Food and Drug Administration has stated that Prussian Blue is safe and effective in treating people exposed to cesium-137 and that Ca-DTPA and Zn-DTPA are safe and effective for treatment of internally deposited plutonium, americium, and curium (21). If it is suspected that the patient may have been exposed to radioiodine, potassium iodide (KI) should be administered to help protect the thyroid gland (Table 6) (17,20,22,23). It should be noted that with the exception of KI, which is very effective if used early after exposure to radioiodines, most decorporation agents will reduce the effective dose from radiation to the patient by a factor of only 3 or less.

Acute Radiation Syndrome

Acute radiation syndrome (ARS) (i.e., radiation sickness) is rare but may present as an acute illness in patients after exposure to very large doses (> 100 rem) of radiation. ARS is extremely unlikely to occur in staff treating patients who are contaminated with radioactive material. ARS follows a roughly predictable course over a period of time ranging from a few hours to several weeks (Table 7) and is described in many references (9,14,24). The severity of the syndrome 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, genetics, and medical conditions. If it is believed that the victim may have received a high radiation dose (e.g., > 50 rem), a complete blood cell count with absolute lymphocyte count should be taken initially and about every 6 h thereafter (Table 3). Chromosomal analyses of lymphocytes are performed by specialized laboratories and typically require days for results to be reported. REAC/TS can assist with locating the appropriate facilities (4). Results of these tests may be used to estimate the radiation dose and the severity of radiation injury.

The signs and symptoms that develop in ARS occur in four distinct phases: prodromal (initial), latent period, manifest illness stage, and recovery or death (Table 7). During the prodromal phase, symptoms including loss of appetite, nausea, vomiting, fatigue, and diarrhea should be treated in a routine clinical manner. The severity and time of onset of symptoms should be recorded. For doses in the range of 100–800 rem to most of the body, the manifest illness stage begins in less than 2 weeks and is mainly caused by damage to the hematopoietic system, resulting in decreased blood concentrations of leukocytes and platelets, which cause an increased risk of infection and bleeding. For doses above about 800 rem, the latent period is on the order of 1 to 3 days and the primary effects are due to damage to the lining of the intestines, with diarrhea, fever, sepsis, and electrolyte disturbances. Survival, even with medical treatment, is highly unlikely for doses above about 1000 rem. For even higher doses, exceeding about 3000 rem, there is little or no latent period. The patient soon becomes confused, with severe diarrhea and hypotension, and death occurs in a day or two.

Treatment of ARS should focus on prevention of infection. Antibiotics for neutropenia and fever should be guided by the recommendations of the Infectious Diseases Society of America (25). Routine gut prophylaxis should not be administered (24). Hematopoietic growth factors should be given within the first 24–48 h and then daily. Patients with severe ARS will require hospitalization. Several books and papers provide guidance on the management of ARS (2,9,14,24). REAC/TS and the Medical Radiobiology Assistance Team of the Armed Forces Radiobiology Research Institute (AFRRI) can provide guidance 24 h a day on patient assessment and management of ARS (Table 8).

Patients who have suffered trauma combined with an acute high-level radiation exposure will have increased morbidity as compared to patients who have received the same dose of radiation without trauma. If a patient has received an acute radiation dose > 100 rem, 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.

Local Radiation Injury

Radiation exposure to parts of the body can cause localized effects if the dose is sufficiently high, typically > 200 rem. The patient may not be aware that he or she was exposed. Such a patient may have localized burn-like skin injuries without a history of heat exposure. Epilation of the exposed area may occur. These symptoms do not appear immediately but rather days after exposure. A tendency to bleed, nausea and vomiting or other symptoms of ARS may be present. If a patient presents with burns immediately after a terrorist event, such as a dirty bomb, it is more likely that the burns are thermal burns, not radiation burns.

OTHER HEALTH EFFECTS OF RADIATION

Studies of animals and epidemiologic studies of humans, particularly the survivors of the atomic bombings in Japan, have shown that radiation is a weak carcinogen. The International Commission on Radiological Protection has estimated the lifetime risk of fatal cancer, for

Table 5. Substances Suitable for Decorporation Treatment

Medication	Trade Name	Elements	Dosage Schedule*	Relative Effectiveness with Time	Principle of Action	Side Effects	Contraindications
DTPA (diethylene triaminepentaacetic acid, Ca or Zn) (21)	N/A	Am, Cf, Cm, Pu	Adults: 1 g/d by slow i.v. push or infusion in 250 mL 5% glucose. Inhalation in a nebulizer: 1 g/d Pediatrics (< 12 years): 14 mg/kg/d by slow i.v. push or infusion in 250 mL 5% glucose Ca-DTPA for initial treatment (24 h) followed by Zn-DTPA for protracted therapy.	Should be started as soon as possible. Efficacy greatest within 6 h of exposure.	Chelation	Monitor blood pressure during infusion. Monitor for kidney function, liver enzymes and signs of intestinal damage. Can be used for wound cleaning. May need trace metal supplements for prolonged therapy.	Ca-DTPA contraindicated for patients with kidney, intestinal or hematopoeitic disorders, pregnant women and minors.
KI (potassium iodide)	Thyroblock, Iostat and others	I	130 mg/day oral†	50% effective at 6 h. Only 7% effective if given at 24h.	Blocking	Angioedema if sensitive to I; Treat w/ perchlorate, 1 $\times$ 200 mg, then 100 mg every 5 h.	Caution with goiter or hyperthyroidosis; Do not treat the elderly.
Prussian Blue (ferric hexacyanoferrate) (21)	Radiogardase	Cs	Adults and adolescents: 3 grams orally three times daily. Pediatrics (2–12 years): 1 gram orally three times daily.	Most effective when given promptly but continues to be effective in preventing recycling of radionuclide in the intestine.	Adsorption	Constipation. May affect absorption of other medications including tetracycline.	Only effective if GI motility is intact.
A) Aluminum phosphates	A) Aluminum containing antacids	Sr	A) 100 mL gel (13 g) oral	A & B) Most effective if given immediately.	A & B) Adsorption	A&B) Constipation. Possible interactions with other medications including tetracycline.	A&B) Diabetics: May contain glucose.
B) Alginates	B) Gaviscon		B) 10 g oral then 4 g per day				
C) NH_4Cl (ammonium chloride) plus Calcium gluconate			C) 1–2 g NH_4Cl every 6 h oral plus 500 mg Ca gluconate in 500 mL 5% glucose in water over 4 h i.v.	C) Still effective up to 2 wks after exposure.	C) De-mineralization	C) Gastric irritation.	C) Ca gluconate should not be given to patients with heart conditions.

Table 5. (Continued)

Medication	Trade Name	Elements	Dosage Schedule*	Relative Effectiveness with Time	Principle of Action	Side Effects	Contraindications
$NaHCO_3$ (sodium bicarbonate)	N/A	U	4 g oral initially; 2 g every 4 h until urine pH of 8–9 is maintained.		Complexation	None	
Penicillamine	Cuprimine, Depen	Heavy Metals including Cu, Fe, Hg, Pb, Au, Po	250–1500 mg every 8 h oral		Chelation	Maculopapular or erythematous rash, marrow suppression, kidney function, immune-related diseases.	

* Consult REAC/TS (4) or the Physicians Desk Reference (PDR) for information on pediatric dosages not provided.
† See Table 6 for additional information.

working age adults exposed to low doses of radiation, to be about 5×10^{-4} deaths per rem (26). For doses likely to be received by staff in the ED (< 1 rem), the increased risk of cancer is minimal.

Radiation-induced hereditary (genetic) effects have been demonstrated in animals, but direct evidence of radiation-induced hereditary effects has not been observed in any of the studies of humans exposed to radiation, even after high doses of radiation (27). For doses likely to be received by staff, the risk is minimal. 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 (27). The natural incidence of genetic disease and malformations at 1 to 2 years of age is 6–10% (28).

Studies of animals and humans have shown that prenatal radiation exposure can cause teratogenic effects (27,29–31). However, there is no evidence of an increased incidence of such effects for doses < 10 rem to the embryo or fetus. Also, some epidemiological studies of humans indicate that radiation-exposure to the embryo or fetus may increase the incidence of post-natal cancer (29). Although it is quite unlikely that someone providing care for a radioactively contaminated patient would receive a large dose, as a precaution, the Centers for Disease Control and Prevention (CDC) recommends excluding pregnant staff from such cases whenever possible (8). Fetal doses would have to be > 10 rem before abortions were considered and, then, only on advice from a physician with expertise on radiation and pregnancy (32).

RADIATION DOSE LIMITS FOR EMERGENCY WORKERS

There are several recommendations for radiation dose limits to emergency workers performing lifesaving actions. Although the U.S. Nuclear Regulatory Commission does not have a limit for emergency lifesaving actions (i.e., immediate response to a life or death situation), the National Council on Radiation Protection and Measurements (5) and the International Council on Radiation Protection (26) recommend that doses can approach or exceed 50 rem. Although this dose is 10 times higher than annual occupational dose limit, it represents a modest increase in cancer risk compared to the large benefit to the recipients of the lifesaving measures. Emergency workers should perform these lifesaving activities voluntarily and with prior training regarding the risks of exposure. It is unlikely that the dose to ED staff would approach these levels. The doses ED staff received after the Chernobyl accident were < 1 rem (12).

Table 6. Thyroid Radioiodine Predicted Dose Threshold for Administration of KI for Different Risk Groups (22)

	Predicted Thyroid Dose (rad)	KI Dose (mg)	Number of 130 mg Tablets*	Number of 65 mg Tablets*
Adults over 40 years	≥500	130	1	2
Adults 18–40 years	≥10	130	1	2
Pregnant or lactating women	≥5	130	1	2
Adolescents 12–18 years†	≥5	65	1/2	1
Children 3–12 years	≥5	65	1/2	1
1 mo–3 years	≥5	32	1/4	1/2
Birth–1 month	≥5	16	1/8	1/4

* Take tablet or fraction of tablet orally once a day. Crush for small children. Saturated Solution of Potassium Iodide (SSKI) can be used in place of tablets. SSKI contains 1 gm of KI per mL of solution. 130 mg of SSKI = 0.13 mL, or approximately 3 drops. Dilute in juice.
† Adolescents approaching adult size (> 70 kg) should receive the full adult dose (130 mg).

FACILITY RECOVERY

If the efforts made during facility preparation were successful, facility recovery should be relatively easy. During facility recovery, employee exposures should be kept ALARA. If available, an in-house radiation safety staff member 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 before disposal. Some facilities have portal radiation monitors to survey hospital trash. They provide 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 methods are typically very effective. Facilities should be decontaminated to the extent possible. Gloves, shoe covers, and coveralls should be worn by people decontaminating the area. For some contaminated items, replacement may be more cost effective and practical than decontamination. The decontamination goal for surfaces is to have less than twice the normal background reading. Areas that cannot be decontaminated to this level should be referred to health physics or radiation safety specialists. There are companies that can perform decontamination services.

SUMMARY

In a radiological emergency, medical stabilization and treatment of the patient take priority over decontamination efforts. Radiation exposure and contamination are not likely to be significant hazards to staff. Staff can protect themselves from radioactive contamination by using universal precautions while treating these patients. As opposed to patients who arrive contaminated with chemical or biological agents, radioactive contamination is easy to detect.

Every hospital should have a Radiological Emergency Medical Response Plan that will allow effective handling of contaminated and injured patients. JCAHO requires organizations to have an emergency management plan (7). There are many resources available including books, journal articles, and internet sites that will be useful in preparing a hospital emergency plan (Table 8). Testing the plan through periodic drills (e.g., annually) and the utilization of an effective training program (Table 8) 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). Preparations should ensure that adequate supplies and radiation survey instruments are available. Non-ED staff who can assist in a radiological emergency should be identified and trained in advance. Staff from Nuclear Medicine, Radiation Oncology, and Radiation Safety have expertise in radiation protection practices and the use of survey meters. Measures should be taken to prevent the "worried well" and uninjured people with radioactive contamination from overwhelming the ED and hindering patient care.

Most victims of a mass casualty event involving radioactive material will arrive at the ED with little contamination. ED staff are likely to receive far less than the annual occupational dose limit of 5 rem. The long-term risks from radiation exposures of < 5 rem are very low. Even in an extreme case involving radiation casualties, the Chernobyl nuclear reactor accident in 1986, medical personnel working on the victims received < 1 rem (12). In the case of an RDD, very high dose rates could exist if embedded shrapnel from the RDD was intensely radioactive. This unlikely possibility would be easy to determine with radiation survey instruments.

Most victims of radiation accidents will show no signs or symptoms of radiation exposure due to their small exposures. In the rare instance when victims have received large radiation doses, early signs and symptoms and their inten-

Table 7. Phases of Acute Radiation Syndrome

Phase of Syndrome	Feature	Effects of whole-body irradiation, from external radiation or internal absorption, by dose range in rad (1 rad = 1cGy; 100 rad = 1Gy)					
		0–100	100–200	200–600	600–800	800–3000	> 3000
Prodromal	Nausea, vomiting	None	5–50%	50–100%	75–100%	90–100%	100%
	Time of onset		3–6 h	2–4 h	1–2 h	< 1 h	Minutes
	Duration		< 24 h	< 24 h	< 48 h	< 48 h	N/A
	Lymphocyte count	Unaffected	Minimally decreased	< 1000 at 24 h	< 500 at 24 h	Decreases within hours	Decreases within hours
	CNS function	No impairment	No impairment	Routine task performance	Simple, routine task performance	Rapid incapacitation	
				Cognitive impairment for 6–20 h	Cognitive impairment for > 24 h	May have a lucid interval of several hours	
Latent	No symptoms	> 2 weeks	7–15 days	0–7 days	0–2 days	None	
Manifest illness	Signs, symptoms	None	Moderate leukopenia	Severe leukopenia, purpura, hemorrhage, pneumonia, hair loss over 300 rad		Diarrhea, fever, electrolyte disturbance	Convulsions, ataxia, tremor, lethargy
	Time of onset		> 2 weeks	2 days–2 weeks		1–3 days	
	Critical period		None	4–6 wk; greatest potential for effective medical intervention		2–14 d	1–48 h
	Organ system	None		Hematopoietic, respiratory (mucosal) systems		GI tract, Mucosal systems	CNS
	Hospitalization Duration	0%	< 5% 45–60 days	90% 60–90 days	100% 90+ days	100% Weeks to months	100% Days to weeks
	Mortality	None	Minimal	Low with aggressive therapy	High	Very high; significant neurological symptoms indicate lethal dose	

From (14): Military Medical Operations Armed Forces Radiobiology Research Institute. Medical Management of Radiological Casualties Handbook, 2nd edn. April 2003. Available at: http://www.afrri.usuhs.mil.

Table 8. Resources

Organizations		
Radiation Emergency Assistance Center/ Training Site (REAC/TS)	(865) 576-1005	www.orau.gov/reacts
Centers for Disease Control (CDC)	(888) 246-2675 (888) 246-2857 (Spanish)	www.bt.cdc.gov/radiation/links.asp
Medical Radiobiology Advisory Team (MRAT) of the Armed Forces Radiobiology Research Institute (AFRRI)	(301) 295-0530	www.afrri.usuhs.mil
Books		
Medical Management of Radiation Accidents. Gusev, Guskova and Mettler, CRC Press, 2001.		
Medical Effects of Ionizing Radiation. Mettler and Upton, Saunders, 1995.		
The Medical Basis for Radiation-Accident Preparedness. REAC/TS Conference, 2002.		
National Council on Radiation Protection and Measurements. Report Nos. 65 and 138.		
Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident, National Academy of Sciences (http://books.nap.edu/catalog/10868.html). 2004.		
Booklets/articles		
Disaster Preparedness for Radiology Professionals, Response to Radiological Terrorism (http://www.acr.org and search Disaster Preparedness Primer)		
Guidebook for the Treatment of Accidental Internal Radionuclide Contamination of Workers. Radiation Dosimetry, 41:1–49, 1992.		
Department of Health and Human Services, Food and Drug Administration, Guidance for Industry Internal Radioactive Contamination—Development of Decorporation Agents, March 2006 (http://www.fda.gov/cder/guidance/index.htm)		
Department of Homeland Security Working Group on Radiological Dispersal Device Preparedness, (http://www1.va.gov/emshg/docs/Radiologic_Medical_Countermeasures_051403.pdf), 2003.		
Interim Guidelines for Hospital Response from a Radiological Incident, (http://www.bt.cdc.gov/radiation/pdf/MassCasualtiesGuidelines.pdf), 2003.		
Major radiation exposure—what to expect and how to respond. Mettler FA, Voelz GL. N Engl J Med 2002;346:1554–61.		
Medical management of the acute radiation syndrome: recommendations of the strategic national stockpile radiation working group. Waselenko JK, MacVittie TJ, Blakely WF, et al. Ann Intern Med 2004;140:1037–51.		
Medical Management of Radiological Casualties Handbook, (http://www.afrri.usuhs.mil), 2003.		
OSHA Best Practices for Hospital-Based First Receivers of Victims from Mass Casualty Incidents Involving the Release of Hazardous Substances, http://www.osha.gov/dts/osta/bestpractices/firstreceivers_hospital.html), 2004.		
Training program		
Emergency department management of radiation casualties. Bushberg JT, et al. (http://hps.org/hsc/documents/emergency.ppt), 2004.		

sities will be an indication of the severity of the radiation injury. The first 24 h after an incident will be the most challenging for those involved in the emergency response. After the first day, there will likely be many additional resources arriving from state and federal agencies. Understanding basic radiation protection principles will aid the care providers in effectively and efficiently managing the victims of radiation accidents.

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