INTRODUCTION

Radiation exposure may either be accidental or intentional. The year 2015 marked the 70th anniversary of the bombing of Hiroshima and Nagasaki, with nearly 200,000 acute deaths and untold numbers with chronic disability. Accidental exposures can occur during transport, storage, or working with radioactive materials or with errors in dosing radiotherapy. Most civilian incidents involve industrial exposures from sealed radiation sources. The Fukushima Daiichi nuclear disaster resulted in about 1000 disaster-related deaths; however as of this writing, no deaths were related to radiation exposure.

The largest reported accidental exposure took place in Goiania, Brazil in 1987. An "orphaned" cesium-137 radiosource was left in place at an abandoned radiotherapy institute. Individuals looking for scrap metal removed the source and dismantled it. They proceeded to sell it to a junk dealer, who observed the material glowing in the dark. Due to this unique characteristic, he distributed it to family and friends, who quickly became ill with acute radiation syndrome. At the conclusion of this event, there were 112,000 individuals evaluated for exposures, 249 who were contaminated, 20 who required hospital admissions, and four who died.

A famous case of malicious intentional exposure involved Alexander Litvinenko, a former KGB agent who had defected to England. In 2006, after a meeting with former co-workers, he suffered a protracted gastrointestinal illness with associated leukopenia. On the day of his death, elevated levels of polonium-210 were identified, confirming his death from radiation exposure. Investigations into his murder revealed that there were had been rehearsals in multiple areas of England leading to contamination. The public health response that followed found that there were 1693 local and international individuals who were potentially exposed during such rehearsals.

Radiologic dispersal devices, or "dirty bombs," combine radioactive materials with conventional explosives in attempts to disperse "hot material" over an unsuspecting population. The intended use of these devices is to generate some injuries, but the true goal is to generate massive panic and hysteria, overwhelm local resources, affect the local economy, and lead to prolonged clean-up efforts.

FUNDAMENTALS OF RADIATION PHYSICS

Radiation energy includes the entire electromagnetic spectrum: from low-energy, long-wavelength, and low-frequency nonionizing radiation, such as radio waves and microwaves, to high-energy, short-wavelength, and high-frequency forms of ionizing radiation. Ionizing radiation has enough energy to remove an electron from an atom and generate charged particles. Sources of ionizing radiation are: alpha particles, beta particles, neutrons, and sole energy waves that include x-rays and gamma rays.
Alpha and beta particles and positrons are charged particles that directly interact with electrons of the atom. Neutrons are not charged, and they lead to expulsion of other particles after interactions with the atomic nuclei, so neutrons indirectly generate charged atoms. Gamma and x-rays are electromagnetic waves that destabilize the atomic nucleus and lead to the expulsion of ionized particles (Table 10-1).

<table>
<thead>
<tr>
<th>Type (Symbol)</th>
<th>Charge</th>
<th>Penetration</th>
<th>Shield</th>
<th>Hazard</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>+2</td>
<td>Few centimeters in air</td>
<td>Paper, keratin layer of skin</td>
<td>Internal contamination only; requires special detection devices</td>
<td>Heavy radioisotopes (e.g., plutonium, uranium, radon)</td>
</tr>
<tr>
<td>Beta</td>
<td>−1</td>
<td>~8 mm into skin</td>
<td>Clothing</td>
<td>External (skin) and internal contamination</td>
<td>Most radioisotopes decay by beta followed by gamma emission</td>
</tr>
<tr>
<td>Positron</td>
<td>+1</td>
<td>~8 mm into skin</td>
<td>Lead, steel or concrete</td>
<td>Interacts with electrons and releases photons of energy</td>
<td>Medical tracers</td>
</tr>
<tr>
<td>Neutron</td>
<td>0</td>
<td>Variable</td>
<td>Material with high hydrogen content</td>
<td>Whole-body irradiation</td>
<td>Nuclear power plants, particle accelerators, weapons assembly plants</td>
</tr>
<tr>
<td>Gamma and x-rays</td>
<td>0</td>
<td>Several centimeters in tissue</td>
<td>Concrete, lead</td>
<td>Whole-body irradiation</td>
<td>Most radioisotopes decay by beta followed by gamma emission</td>
</tr>
</tbody>
</table>

**ALPHA PARTICLES**

Alpha particles have relatively large size (two protons and two neutrons), have limited travel potential, and are unable to penetrate the outer layers of the skin. Thus, alpha particles are easily shielded with a piece of paper. Exposure to alpha particles only leads to pathology in the setting of ingestion, inhalation, or absorption. Detection can be problematic because common Geiger counters do not detect alpha particles without a special attachment.  

**BETA PARTICLES**

Beta particles are much smaller (a single electron) than alpha particles. Small size allows for greater penetration ability. Beta radiation can travel several meters in air, penetrates approximately 8 mm into exposed skin, and can cause serious burns. Beta radiation is a hazard if internally deposited. Most radioisotopes decay by beta radiation followed by gamma emission.
POSITRONS

Positrons are positively charged beta particles that are emitted from the atomic nuclei. They are the antiparticles to the electron, and interactions with electrons lead to the generation of highly energetic photons that requires shielding with lead, steel, or concrete. Positron sources are commonly used in medical procedures such as positron emission tomography scanning.  

NEUTRONS

Neutrons are uncharged particles that are capable of generating radiation via alterations of the atomic nuclear proton-to-electron ratio. These particles are capable of traveling large distances and require the use of helium, water, and paraffin as shielding. Neutron exposures are rare and tend to be limited to nuclear fallout, research, industry, and weapons manufacturing.  

GAMMA RAYS AND X-RAYS

Gamma rays and high-energy x-rays are able to travel meters in the air and can penetrate centimeters into human tissue. Shielding materials must be very dense, such as concrete or lead. Individuals exposed to high doses of these sources are at high risk of developing acute radiation syndrome.  

BIOLOGIC EFFECTS OF IONIZING RADIATION

Ionizing radiation leads to cellular effects at both high and low levels of exposure. At high doses, ionizing radiation causes cell death. At lower doses, it interrupts cellular reproduction through inhibition of mitosis, resulting in cellular injury with delayed onset of effects.  

Radiosensitivity refers to the response of cells to radiation injury. Rapidly dividing cells with short life spans are the cells most vulnerable to radiation injury, because they are quickly depleted and new cells are unable to replete the population.  

MEASURING RADIATION

There are many ways in which radiation can be measured: dose given, exposure received, absorbed dose, or activity generated. Many conventional units may be used, and confusion can arise between interchanging units. See Table 10-2 for more information on units of measure.
### TABLE 10-2
Radiation Units of Measure

| Description                                                                 | Conventional Units | SI Unit   | Conversion                              |
|                                                                            |                    |           |                                        |
| Activity                                                                  | Curie              | Becquerel | 1 Bq ~ $2.7 \times 10^{11}$ Ci          |
| Units of activity describe the amount of radioactivity present.           |                    |           | 1 Ci ~ $3.7 \times 10^{10}$ Bq          |
| Exposure                                                                  | Roentgen           | Coulomb per kilogram | 1 R = $2.58 \times 10^4$ cP/kg       |
| Units of exposure measure the amount of x-ray or gamma radiation that produces a given number of ionizations in air. |                    |           |                                        |
| Absorbed dose                                                             | rad                | Gray      | 1 rad = 0.01 Gy                        |
| Units of absorbed dose can be applied to any type of radiation and reflect the energy imparted to matter. |                    |           | 1 Gy = 100 rad                         |
| Dose equivalent                                                           | Roentgen equivalents man | Sievert | 1 rem = 0.01 Sv                         |
| Units that provide a common scale of measure for the different types of radiation. |                    |           | 1 Sv = 100 rem                         |

*Abbreviation*: SI = International System of Units.

**RADIATION MONITORING EQUIPMENT**

Just as there are many radiation units, there are many ways to monitor radiation exposures. Commonly used equipment includes dosimeters and survey meters (*Table 10-3*). In the setting of radiation emergencies, both of these devices should be available to ED staff. Staff should wear dosimeters because of their small size and ability to measure and record an individual's cumulative exposure doses. In contrast, rate meters are survey instruments that record the amount of radiation in an area over a particular time course and are best suited to monitor environmental contamination.
TABLE 10-3

Radiation Monitoring Equipment

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Device</th>
<th>Common Type of Measurement</th>
<th>Units Commonly Recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dosimeter</td>
<td>Thermoluminescent dosimeter or film badge</td>
<td>Cumulative dose of beta, x-ray, and gamma</td>
<td>Roentgen equivalents man or sieverts</td>
</tr>
<tr>
<td>Dosimeter</td>
<td>Pocket dosimeter</td>
<td>Cumulative exposure to x-ray and gamma</td>
<td>Milliroentgen</td>
</tr>
<tr>
<td>Survey meter</td>
<td>Geiger-Müller tube</td>
<td>Low exposure rates of x-ray, gamma, and beta*</td>
<td>Counts per minute†</td>
</tr>
<tr>
<td>Survey meter</td>
<td>Ion chamber</td>
<td>Higher exposure rates of x-ray and gamma</td>
<td>Milliroentgen per hour</td>
</tr>
</tbody>
</table>

* With special instrument probes, alpha radiation can also be detected.

† 2500 counts per minute equal approximately 1 mR/h.

ALLOWED ANNUAL DOSE OF RADIATION

Radiation exposures are an unavoidable hazard of living on our planet. Common sources of unavoidable radiation include cosmic and solar rays, naturally occurring elements such as radon and uranium, and even some of the carbon in our bodies. The background radiation dose of individuals living in the United States is approximately 6.2 mSv (620 mrem). The International Commission on Radiological Protection, the National Commission on Radiological Protection and Measurements, and the Health Physics Society have set the annual radiation dose limit for the general public at 1 mSv per year (100 mrem) over natural background radiation. See Table 10-4 for selected approximate levels of radiation exposure.
TABLE 10-4

Selected Approximate Levels of Radiation Exposure

<table>
<thead>
<tr>
<th>Radiation Source</th>
<th>Approximate Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural background radiation</td>
<td>620 mrem/y (U.S. average)</td>
</tr>
<tr>
<td>Chest x-ray (effective dose)</td>
<td>10 mrem</td>
</tr>
<tr>
<td>Abdominal x-ray</td>
<td>120 mrem</td>
</tr>
<tr>
<td>Lumbar spine x-ray</td>
<td>70 mrem</td>
</tr>
<tr>
<td>CT head</td>
<td>200 mrem</td>
</tr>
<tr>
<td>CT chest</td>
<td>700 mrem</td>
</tr>
<tr>
<td>CT abdomen or pelvis</td>
<td>1000 mrem</td>
</tr>
<tr>
<td>Jet travel</td>
<td>1 mrem per 1000 miles traveled</td>
</tr>
<tr>
<td>Annual radiation dose limit (public)</td>
<td>100 mrem/y*</td>
</tr>
<tr>
<td>Occupational exposure limit</td>
<td>5000 mrem/y</td>
</tr>
<tr>
<td>Lethal dose in 50% of exposed subjects within 60 d</td>
<td>350,000–450,000 mrem (350–450 rad†)</td>
</tr>
</tbody>
</table>

* over natural background radiation.

† 1 rem (dose equivalent) = 1 rad (absorbed dose or exposure).

LETHAL DOSE OF RADIATION

The LD\(_{50/60}\) from exposure to ionizing radiation is defined as the dose of penetrating ionizing radiation that will result in the deaths (lethal dose) of 50% of the exposed population within 60 days without medical treatment. Regarding human survival, the most commonly cited value is an LD\(_{50/60}\) of approximately 3.5 to 4.5 Gy (350 to 450 rad). In the setting of supportive medical therapy, including antibiotics, blood products, and reverse isolation, the value is 4.8 to 5.4 Gy (480 to 540 rad). During mass exposures where resources may be limited to basic first aid, the LD\(_{50/60}\) falls to approximately 3.4 Gy (340 rad). The use of stem cell transplantation and hematopoietic growth factor administration has theoretically increased the LD\(_{50/60}\) to 11 Gy (1100 rad).

CLINICAL EFFECTS OF RADIATION

LOCAL RADIATION INJURY
Most radiation accidents are due to local radiation injury from partial-body exposure. Partial-body irradiation rarely causes systemic manifestations; rather, it leads to a dose-dependent cutaneous involvement. Typically, the injury in the first week tends to be asymptomatic, although there may be transient erythema (6 Gy/600 rad), hyperesthesia, and itching. The second week is characterized by the development of erythema that progresses to hair loss (3 Gy/300 rad). The development of skin tenderness, swelling, and pruritus heralds the third week after exposure. Within the fourth week, the wound will develop dry (10 to 15 Gy/1000 to 1500 rad) or wet (15 to 20 Gy/1500 to 2000 rad) desquamation and/or ulceration (>25 Gy/2500 rad).12

Skin findings may be indistinguishable from thermal burns. Radiation injuries are hallmarked by episodes of transient erythema and delayed onset of prolonged and severe pain. As long as the exposure is less than 50 Gy (5000 rad), these injuries develop over a much longer time period than thermal burns. When doses exceed 50 Gy, these injuries will progress similarly to thermal burns, and the onset of pain will occur immediately. Surgical intervention such as resection and grafting may be required.

**ACUTE RADIATION SYNDROME**

Acute Radiation Syndrome occurs after a significant exposure to penetrating ionizing radiation within a 24-hour time period (Table 10-5). It should be expected in cases in which a whole-body gamma dose exceeds 2 Gy (200 rad). External sources of alpha and beta radiation are unable to penetrate the body, although internal contamination may lead to this syndrome. Neutron sources, although rarely encountered, can also lead to acute radiation syndrome.

<table>
<thead>
<tr>
<th>Approximate Dose</th>
<th>Onset of Prodrome</th>
<th>Duration of Latent Phase</th>
<th>Manifest Illness</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2 Gy (200 rad)</td>
<td>Within 2 d</td>
<td>1–3 wk</td>
<td>Hematopoietic syndrome with pancytopenia, infection, and hemorrhage; survival possible</td>
</tr>
<tr>
<td>&gt;6 Gy (600 rad)</td>
<td>Within hours</td>
<td>&lt;1 wk</td>
<td>GI syndrome with dehydration, electrolyte abnormalities, GI bleeding, and fulminant enterocolitis; death likely</td>
</tr>
<tr>
<td>&gt;20–30 Gy (2000–3000 rad)</td>
<td>Within minutes</td>
<td>None</td>
<td>Cardiovascular/CNS syndrome with refractory hypotension and circulatory collapse; fatal within 24–72 h</td>
</tr>
</tbody>
</table>

Acute radiation syndrome develops in four distinct phases: prodrome, latent phase, manifest-illness, and recovery. The initial prodrome involves the transient autonomic nervous system response to the exposure. It is directly related to the dose received. High doses cause acute and severe symptom onset, whereas lower doses may lead to prolonged onset and milder symptoms. Nausea, vomiting, anorexia, and diarrhea may be accompanied by hypotension, pyrexia, diaphoresis, cephalgia, and fatigue.

The prodrome is followed by the latent phase, a symptom-free interval whose duration depends on the received dose. Larger doses result in a shorter duration of this phase. Doses less than 4 Gy are associated with a period that may last 1 to 3 weeks, whereas in doses greater than 15 Gy, this phase may only last a few hours.
The manifest-illness phase is subdivided into three dose-dependent syndromes that are hallmarked by the affected organ system. The syndromes are not independent of one another, and there is synergy and overlap leading to the clinical manifestations. The final stage is recovery.

**Hematopoietic Syndrome** The hematopoietic system is the first organ system that demonstrates injury when doses exceed 1.5 Gy. The prodromal phase of this subsyndrome occurs within hours to a few days from the exposure, resolves within 48 hours, and is followed by a latent phase that on average lasts 1 to 3 weeks.

Radiation damages the bone marrow stem cells and destroys circulating hematopoietic cells, particularly lymphocytes (Figure 10-1). Because of the preferential destruction of lymphocytes, the peripheral lymphocyte count is currently the best marker to grade the extent of the injury. Granulocytes and platelets are also affected. However, being markers of inflammation, their counts rise in the immediate time period following the exposure, and later decline and reach a nadir within 30 days of the injury. Red blood cells are also affected but not to the same extent of the other lines due to the lack of nuclear material. Morbidity and mortality depend on associated pancytopenia, immunosuppression, and hemorrhage. Aggressive medical management with blood products and growth factors may increase survival.

**GI Syndrome** Doses greater than 6 Gy (>600 rad) cause the GI syndrome. Nausea, vomiting, and diarrhea develop within hours of exposure. This is followed by a short latent phase lasting up to 1 week. The manifest-illness phase is characterized by the recrudescence of severe nausea, vomiting, diarrhea, and abdominal pain. The initial insult leads to the apoptotic death of the GI mucosa, with associated insult to the underlying stem cells responsible for their replenishment. Impaired mucosal integrity causes massive fluid and electrolyte losses and allows the translocation of enteric flora into the bloodstream. Fulminating enterocolitis results.

**Cardiovascular and CNS Syndrome** The last subsyndromes of the manifest-illness phase are the cardiovascular and CNS syndromes, resulting from doses greater than 20 to 30 Gy (>2000 to 3000 rad). There is immediate hypotension, prostration, nausea, vomiting, and explosive bloody diarrhea. Hypotension is persistent and unresponsive to treatment. CNS symptoms manifest within hours and include seizures, lethargy, disorientation, ataxia, and tremors. The lymphocyte count, the quickest marker available to determine the extent of injury, very quickly falls to near-zero levels. Death from circulatory collapse ensues within 72 hours.
EMERGENCY RESPONSE PLANNING

Emergency response plans should involve multiple community-wide organizations, including hospitals, EDs, public safety, public health, and emergency management officials. Every EMS system should have a prehospital plan for the evacuation of victims from a radiation disaster. Every hospital is required by The Joint Commission to have a written protocol detailing instructions for receiving and treating radiation victims. Hospitals should stage regular disaster drills and train personnel in decontamination procedures, use of personal protective equipment, and radiologic monitoring. Planning templates exist to assist hospitals in developing appropriate radiation emergency response plans.\textsuperscript{13,14}

PREHOSPITAL EMERGENCY MEDICAL MANAGEMENT

Emergency responders should rapidly establish incident command in a situation involving radioactive materials. Personal protective equipment and respiratory protection should be used as the situation dictates. Care and transportation of seriously injured victims should not be delayed, even if the patient is contaminated. In medically stable patients, perform radiation monitoring and decontamination at the scene.

ED NOTIFICATION AND PREPARATION

First responders must communicate with hospitals prior to arrival to allow adequate preparation. Provide incident information such as circumstances of the event, number of victims, type of radiologic insult, and identification of radioactive material (if known). Coexisting medical conditions and traumatic injuries need to be reported. Extent of completed patient decontamination should also be relayed. The hospital disaster plan should include steps that need to be initiated by the ED upon notification to prepare for a radiologic event (Table 10-6).
TABLE 10-6

ED Preparation

Initiate hospital disaster plan.
- Mobilize hospital radiation experts (radiation safety officer, nuclear medicine and radiation oncology experts and staff).
- Request dosimeters for staff and radiation monitoring and survey instruments.

Prepare the ED.
- Establish an ad hoc triage area based on the location designated in the hospital disaster plan.
- Establish a "contaminated" area and "clean" area separated by a buffer zone using ropes, tape, and signs to designate areas.
- Remove contaminated outer garments when leaving contaminated area and have your body surveyed with a radiation meter prior to leaving the area.
- Cover floors with plastic or paper secured with heavy tape.
- Remove pregnant women, nonessential personnel, and nonessential equipment.
- Request extra gloves, other medical supplies, and extra large plastic bags for disposal.

Use standard precautions to protect staff.
- Staff should wear a water-resistant gown, cap, and shoe covers to keep contaminants off skin and clothes.
- Double glove with inner glove taped in place, changing the top pair after handling contaminated items and between patients.
- N95 masks, if available, are recommended, but surgical masks should be adequate.
- Survey hands and clothing at frequent intervals with a radiation meter.
- Dosimeters, if available, should be worn at the collar, under protective clothing.

The hospital protocol should instruct ED personnel how to contact predetermined local radiation specialists and health physics professionals. These specialists may assist by monitoring radiation doses of personnel, surveying personnel and areas for contamination, directing contamination control and decontamination efforts, and disposing of contaminated wastes. If radiation monitors are not available, patients should undergo decontamination and then be surveyed for residual contamination when monitoring equipment is available.

TRIAGE PRINCIPLES

When there are multiple victims, field triage protocols will designate patients as minor, delayed, immediate, or deceased depending on physical trauma or burns. Do not alter triage principles based solely on radiation exposure. Because radioactive contamination is never immediately life-threatening, do not delay treatment of life-threatening injuries for radiologic surveying. Morbidity and mortality from ionizing radiation injuries increase dramatically in the face of physical trauma, thermal burns, and other significant medical conditions. In a mass-casualty event that could include blast injuries in addition to radiologic insult, resources may be limited and will require a coordinated approach to develop the best management plan.

TREATMENT

Because most radiation injuries are not immediately life-threatening, there is usually time to determine whether the patient was irradiated, externally contaminated, or internally contaminated. Early treatment decisions are based on the
signs and symptoms evident in the first 24 to 48 hours and corresponding laboratory test results.\textsuperscript{15,16} Figure 10-2 illustrates the medical treatment prioritization for those exposed to and/or contaminated with radioactivity.

FIGURE 10-2.
Medical treatment flow diagram for those exposed to or contaminated with ionizing radiation. [Diagram used with permission of Radiation Emergency Assistance Center/Training Site (REAC/TS), Oak Ridge, TN, under contract number DE-AC05-06OR23100 between the U.S. Department of Energy and Oak Ridge Associated Universities.]
DECONTAMINATION OF EXTERNALLY CONTAMINATED PATIENTS

It is highly unlikely that the radioactivity from a contaminated patient would pose a significant risk to healthcare personnel. However, the goal of decontamination measures is to decrease total exposure of the patient and staff, by minimizing radiation exposure from a source external to the body to a level that is as low as reasonably achievable (Table 10-7). This is accomplished by minimizing time of exposure and the quantity of radioactive materials in the area, as well as maximizing distance and shielding from the source.\(^\text{16,17}\)

**TABLE 10-7**

Steps of Patient Decontamination

- Assess external contamination.
- Contact radiation safety officer.
- Assess contamination with radiation survey meter (Geiger counter).
- Evaluate for radioactive shrapnel. Easily accessible pieces should be removed with a forceps and placed in a lead container.
- Document contamination pattern on a body diagram.
- Swab each nostril separately to estimate level of internal contamination of the lungs.
- Decontaminate whole body.
  - Carefully cut and roll clothing away from the face to contain contamination.
  - Double bag clothing and label as hazardous waste.
  - Wash wounds first with saline or water.
  - If facial contamination is present, rinse as appropriate.
  - Gently cleanse intact skin and avoid scrubbing.
  - Repeat patient scan with radiation survey meter. Repeat washing until radiation is <2 times background. Avoid scrubbing.
  - Cover wounds with waterproof dressing.

ACUTE RADIATION SYNDROME

Direct treatment of the irradiated patient toward alleviating the symptoms of the prodromal phase. Pain can be managed with acetaminophen and opioids. Because the patient may be at risk for significant GI bleeding if the exposure dose is more than 5 to 6 Gy, avoid using nonsteroidal anti-inflammatory agents.\(^\text{8}\) Administer antiemetics for nausea and vomiting. Ondansetron or other 5-hydroxytryptamine-3 antagonists are effective.\(^\text{18}\) Use antidiarrheal agents as needed.
Complete laboratory testing as soon as possible. Biologic dosimetry uses laboratory analyses (e.g., rate and nadir of lymphocyte depletion) and clinical signs to estimate absorbed dose. Cytogenetic analysis for chromosomal aberrations (dicentrics) is the gold standard for biodosimetry. Contact the Radiation Emergency Assistance Center/Training Site for assistance with obtaining chromosomal testing.

Perform a targeted history and physical exam. Note time of onset of all symptoms, especially vomiting and diarrhea, which are important in biologic dosimetry. Observe for abnormal vital signs suggestive of acute radiation syndrome, including fever, hypotension, tachycardia, and tachypnea. Monitor for impaired level of consciousness, ataxia, motor or sensory deficits, reflex abnormalities or papilledema, abdominal tenderness, and GI bleeding.

Obtain a baseline CBC with differential and absolute lymphocyte count in the ED and check a CBC every 6 hours for 24–48 hours. Monitor the CBC for progressive declines in lymphocytes as an indicator of total dose. Also obtain a baseline serum amylase and C-reactive protein, because dose-dependent increases are expected after 24 hours in a significant exposure. If vomiting and diarrhea occur in the first 2 to 3 hours (dose estimated to >2 Gy), consider the need for human leukocyte antigen typing in anticipation of pancytopenia requiring further management. This could include administration of blood products, cytokines, colony-stimulating factors, bone marrow cells, or stem cell transplant.\(^\text{19}\) The goal is to bridge cytopenic gaps and manage subsequent infections. Patients may require antibiotics, antifungals, and antivirals during their course.

Monitor patients with large exposures who survive the acute phase for severe infectious and metabolic complications. Treat multiorgan failure from a large radiation exposure with standard supportive measures.\(^\text{20}\)

**LOCAL RADIATION INJURY**

Analgesia is important in the early management of cutaneous radiation injury. Cutaneous radiation injury differs from thermal burns in that the cutaneous injury continues to evolve and may not be visible to the naked eye. The primary goal of treatment is interruption of radiation-induced inflammation in the dermis. Perform traditional burn care, including burn dressings, surgical debridement, and grafting, when indicated. Consider applying topical steroids to control local inflammation\(^\text{16}\) and giving vitamin A, C, and E supplementation, and pentoxifylline to decrease blood viscosity and increase blood flow.\(^\text{17}\) Systemic steroids are not recommended.\(^\text{20}\) Although inpatient treatment may not be always be required, close follow-up is essential given the potential for ongoing evolution of cutaneous injury.

**INTERNALLY CONTAMINATED PATIENTS**

Internal contamination generally does not produce early symptoms but should be considered if persistently high radiation survey readings are noted and with all nose or mouth contamination cases. Obtain a 24-hour urine collection for possible radionuclide identification. Collect other specimens depending on exposure with or without contamination (Table 10-8). Consult radiation experts for treatment with cathartics, activated charcoal, gastric lavage, and radionuclide-specific decorporation agents (Table 10-9). Duration of therapy is based on dose estimations from radiochemical measurements of urine and fecal samples.
<table>
<thead>
<tr>
<th>Specimen/Type of Analysis</th>
<th>Reason</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Suspected radiation exposure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check a CBC every 6 hours for 24–48 hours</td>
<td>Establish baseline and assess lymphocyte depletion as an early predictor of dose.</td>
<td>Venipuncture</td>
</tr>
<tr>
<td>Serum amylase and CRP, repeat daily for 3 days</td>
<td>Parotid glands are sensitive to radiation; amylase will rise if exposed to &gt;0.5 Gy.</td>
<td>Venipuncture</td>
</tr>
<tr>
<td>Urine: routine urinalysis</td>
<td>Establish baseline kidney function, especially if internal contamination is suspected.</td>
<td>Clean catch</td>
</tr>
<tr>
<td><strong>Suspected external contamination</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swabs of body orifices and samples from dressings/wounds</td>
<td>Assess internal contamination and identify radionuclide.</td>
<td>Use separate saline or water-moistened swabs to wipe the inside of each nostril, ear, and mouth.</td>
</tr>
<tr>
<td><strong>Suspected internal contamination</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urine bioassay: 24-h specimen; repeat for 4 d</td>
<td>Radionuclide identification.</td>
<td>Standard specimen containers</td>
</tr>
<tr>
<td>Consider feces bioassay in consult with radiation expert</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CRP = C-reactive protein; REAC/TS = Radiation Emergency Assistance Center/Training Site.
### TABLE 10-9

**Internal Contamination Treatment**

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Ionizing Radiation</th>
<th>Treatment</th>
<th>Mechanism of Action</th>
<th>Usual Administration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iodine (I-131)</td>
<td>β, γ</td>
<td>Potassium iodide</td>
<td>Block thyroid uptake</td>
<td>130 milligrams PO for adults</td>
</tr>
<tr>
<td>Plutonium (Pu-239)</td>
<td>α</td>
<td>Ca-DTPA or Zn-DTPA</td>
<td>Chelation</td>
<td>1 gram in 250 mL NS or 5% dextrose in water over 60 min</td>
</tr>
<tr>
<td>Tritium (H-3)</td>
<td>β</td>
<td>Water</td>
<td>Dilution</td>
<td>Oral: 3–4 L a day for 2 wk</td>
</tr>
<tr>
<td>Cesium (Cs-137)</td>
<td>β, γ</td>
<td>Prussian blue</td>
<td>Decrease GI uptake</td>
<td>1 gram in 100–200 mL water three times a day for several days</td>
</tr>
<tr>
<td>Uranium (U-235)</td>
<td>α</td>
<td>Bicarbonate</td>
<td>Urine alkalinization</td>
<td>2 ampules in 1 L NS at 125 mL/h</td>
</tr>
</tbody>
</table>

*Abbreviations: DTPA = diethylenetriamine pentaacetate; NS = normal saline.*

### PRENATAL EXPOSURES

Fetal sensitivity to radiation depends on a number of factors, including radiation dose and gestational age. The radiation dose to the fetus may not be the same as the dose to the mother, because the fetus is shielded in part by the uterus and surrounding tissues. External exposure of alpha and beta particles is unlikely to reach the fetus, but gamma and x-rays directed toward a pregnant woman's abdomen could harm the fetus. In addition, internal contamination could expose the fetus to higher radiation, because the radioactive material could accumulate in the bladder of the pregnant woman.

The health effects of radiation on the fetus are dependent on the gestational age. Before about 2 weeks of gestation, there is an all-or-none phenomenon, and if the exposure does not result in death of the embryo, no observable effects would be expected. An exposure of greater than 0.1 Gy is expected to be lethal, resulting in resorption of the conceptus. From 2 to 8 weeks, organogenesis occurs. During this time, the embryo is at risk for congenital malformations and growth retardation. In cases of substantial exposures, there is a significant risk of major malformations of the neurologic and motor systems. After 8 weeks of gestation, most organogenesis is complete with the exception of the CNS. Exposures during this period have an increased risk of mental retardation and miscarriage. Throughout gestation, an exposure of less than 0.05 Gy would not be expected to produce an increased risk of noncancer health effects. Consult with radiation medicine physicians regarding fetal dose estimation and risk assessment counseling for the expecting parents. For additional discussion, see chapter 99, Comorbid Disorders in Pregnancy.

### SOURCES OF ASSISTANCE
Two organizations provide medical advice for the treatment of radiation casualties. The Radiation Emergency Assistance Center/Training Site, sponsored by the Department of Energy and managed by the Oak Ridge Institute for Science and Education, provides training programs, consultation assistance, and treatment capabilities, and can dispatch an emergency response team of health professionals to assist at an accident site. After initial treatment and decontamination actions are complete, the Radiation Emergency Assistance Center/Training Site may also accept severely contaminated or irradiated patients for transfer to its facilities for more definitive care.

**Radiation Emergency Assistance Center/Training Site (REAC/TS)**

Oak Ridge Institute for Science and Education

P.O. Box 117, MS 39, Oak Ridge, TN 37831-0117

865-576-3131 (daytime phone; ask for REAC/TS)

865-576-1005 (24-hour emergency number)

Another organization available for consultation is the Medical Radiobiology Advisory Team, sponsored by the Department of Defense and managed by the Armed Forces Radiobiology Research Institute.

**Medical Radiobiology Advisory Team**

Armed Forces Radiobiology Research Institute

National Naval Medical Center

8901 Wisconsin Avenue, Building 42

Bethesda, MD 20889-5603

301-295-0316

301-295-0530 (24-hour emergency number)


**REFERENCES**


