

Chapter 4

Radiological Terrorism

Features of Radiological Terrorist Attacks

Radiological terrorism is the use of radioactive material to cause human casualties, environmental destruction and maximum disruption, panic and fear (1) in the general population for political purposes. Since the atomic bombing of Hiroshima in 1945, with 150,000 casualties and 75,000 fatalities (2), people have feared nuclear explosives more than any other weapons of mass destruction, because of the ability of these weapons to cause immediate devastation and trauma, and because radiation, undetected by human senses, can cause ongoing morbidity and mortality, including cancer, years after exposure (3).

Adding to this fear is the worldwide public awareness of the consequences of accidents involving radiation. From 1944 to 2002, in the United States, 243 radiation accidents occurred, causing 1,342 casualties meeting the criteria for significant radiation exposure (4). Worldwide, over the same period, 403 radiation accidents caused 133,617 casualties, with nearly 3,000 significant exposures and 120 deaths (4). In 1987, in Goiania, Brazil, an incident involving a medical source of radioactive Cesium (^{137}Cs) contaminated 200 people, 20 significantly, resulting in four deaths (4). The public is quite familiar with the 1986 Chernobyl reactor accident, which exposed over 116,500 people and caused at least 28 fatalities due to acute radiation sickness (4). Although these experiences have made the public aware and fearful of the potential harmful effects of radioactive material, they have also given us some knowledge in the evaluation and management of radiation victims.

Radioactive materials, used in industry and health care, are ubiquitous. Authorities have already confiscated radioactive materials from sellers in international black markets (5). Although detonating a nuclear bomb is the worst possible scenario, terrorists can use radioactive materials to fabricate other less lethal, but effective weapons. This chapter will discuss the five potential types and sources of radioactive weapons (1,3):

- Simple radiologic device (SRD): placement of an unshielded, high-level radioactive substance in a public place
- Radiological dispersal device (RDD), also known as a dirty bomb. These bombs use a conventional explosive to disperse radioactive material

- Sabotage of a commercial nuclear reactor
- Homemade nuclear weapon
- Nuclear weapon stolen from the military arsenal of a nuclear power

Simple Radiologic Devices

A SRD is the easiest type of weapon for terrorists to assemble. Surreptitiously, terrorists could place a device containing a high-energy radioactive source in one location, or they could simply spread the material by hand or aerosol in a highly populated area, such as an airport, train station or arena, to expose a maximum number of people (1). Similar to a biological attack, the impact of an attack using a SRD is likely to be covert and delayed. Like biological agents, radioactive exposures do not have an immediate impact due to an interval between exposure and the onset of illness. At lower exposure doses, the onset of clinical symptoms may occur after several weeks (4). Consequently, the most likely responders to SRD attacks will be family physicians and other health care providers, when patients present to primary care offices and emergency departments after developing symptoms. Following an SRD attack, the resulting symptoms and interval between exposure and symptom onset would be a function of the exposure dose, which, in turn, is a function of the radioactive source material, the distance from the exposed person to the source, the length of time exposed to the source and the level of shielding from the source (5).

Recent experience suggests that the use of a SRD, intentional or unintentional, is a plausible scenario. One potential SRD source is radioactive Cesium (^{137}Cs), which has many industrial and medical uses. Industry uses ^{137}Cs in highway construction in devices that measure the density of asphalt. In the Southeast United States, several of these devices have been missing or stolen, with their location unknown (1). The 1987 incident in Goiânia, Brazil occurred after thieves stole a ^{137}Cs therapy source, still contained in its shielding, from a hospital, and sold it for scrap metal. Other involved individuals then broke up the source and shared it. None of the people involved was aware that the device was harmful, and authorities did not detect the incident for 15 days. By that time (1):

- Two hundred and forty-nine persons had been contaminated (out of 112,800 people screened)
- One hundred and twenty of those had external contamination on clothes and shoes
- One hundred and twenty-nine had external and internal contamination
- Twenty required hospitalization
- 14 developed bone marrow depression
- Eight required treatment with granulocyte-macrophage-colony stimulating factor
- Four died from hemorrhage and infection

(From Leikin JB, et al. (1) Reprinted with permission from Elsevier)

Stolen radioactive sources, specifically ^{60}Co (radioactive cobalt), have caused injuries elsewhere, including Juarez, Mexico, and Thailand. Within the United

States, thieves stole sixteen brachiotherapy sources of ^{137}Cs from a hospital in North Carolina and an industrial radiography source of ^{192}Ir (radioactive iridium) in Florida. Authorities have not recovered the materials (1).

Some elements used in SRDs have chemical as well as radiological toxicity. For example, cesium, an alkali metal, will explode if exposed to water. Cesium hydroxide, a strong base, is quite corrosive, and can attack glass. Clinicians and responders will need to be aware of the spectrum of risk posed by chemicals used in SRDs and other devices (1).

Radiologic Dispersal Devices

Radiologic dispersal devices (RRDs) would also be relatively easy for terrorists to assemble. RDDs, also known as “dirty bombs,” are simply conventional explosives attached to radioactive materials (1,5,6). Common radioactive materials, such as ^{137}Cs , are potential sources for dirty bombs. Once detonated, the RDD can contaminate a large area, but because the material is widely dispersed, the level of contamination at any specific location would likely be small. People close to the site of the explosion, however, might suffer physical, potentially lethal injuries from the blast as well as greater radiation doses. For most victims, aside from blast injuries, external contamination with radiologic particles would be the primary problem. Health care providers responding to the victims should consider all exposed victims externally contaminated and at risk for skin injury from beta particles, described later in this chapter. In addition, all victims would require assessment for potential internal contamination through inhalation or absorption through wounds (5).

Based on computer modeling, detonation of a dirty bomb containing materials such as ^{137}Cs or ^{192}Ir would probably not have a large direct effect on the health of an exposed population. Aside from physical blast injuries, most people exposed would receive less than 100 mrem (millirem) of radiation exposure, which would provide a chronic disease risk of about 1/20,000, equivalent to smoking 100 cigarettes. Those few in the highest exposed group who received 5,000 mrem would suffer chronic risks equivalent to a long-term smoker’s risk of cancer. Health care providers treating exposed patients could reduce the exposure levels by removing clothing and washing residual contamination off the skin. Of course, terrorists would probably not announce that the bomb they detonated contained radioactive material. Until authorities detected the radioactive source, other than the immediate blast effects, the radiological injuries could be covert and delayed, determined only when patients developing symptoms arrived at physician offices and emergency rooms after an incubation period.

Although the long-term health risks resulting from detonation of a RDD are relatively small, anxiety and fear associated with even low-level radioactive contamination could have significant economic and social consequences. Following the Goiânia, Brazil incident, concerns over radioactive contamination led to a decrease in agricultural sales of 20% and a 15% decrease in the gross domestic product

(GDP) of Brazil's Goiás State, with GDP levels not returning to preincident levels for 5 years (6).

Although assembling dirty bombs is not difficult, the process involves some risk. Commercial radioactive sources of substances such as ^{137}Cs and ^{192}Ir are powerful enough to present a hazard during assembly and transport of a device. To turn the material into an effective RDD, terrorists would have to remove the radioactive material from its shielding so it could be dispersed by the explosive. Exposure to such unshielded material for an hour at a distance of 1 m would provide enough radiation exposure to cause death without medical care. Although this type of exposure would not prevent many terrorists from assembling such a device, it would create problems for processing, handling and storing the device, and would make it easier for authorities to detect the source during processing and transport (6).

Nuclear Reactor Sabotage

Fortunately, for a couple of reasons, the likelihood of a terrorist attack on a nuclear reactor is quite low. Nuclear reactors operate under tight security and incorporate safety systems. In addition, the extensive shielding around reactors would require large amounts of explosives to create a breach. Even if terrorists could transport large amounts of explosives, they would have to breach a security cordon to reach the reactor. Alternatively, they could commandeer a jumbo jet plane to crash into a reactor or a nuclear pond of used cores, but they would have to breach security measures to do so. Computer modeling indicates that the construction of most reactors would sustain a 300 mph impact from a commercial aircraft, but not all scientists agree with these findings (1).

Even if terrorists succeeded in detonating an explosive at a reactor site, the health consequences would be limited. The reactor accident at the Three Mile Island, Pennsylvania nuclear power plant caused a small release of radiation, insufficient to cause any radiation injuries. Bypassing several safety systems caused the Chernobyl reactor incident, involving two explosions, fires and reactor core meltdown. This accident caused the following early phase health effects (1):

1. Two hundred and thirty-seven hospitalizations
2. One hundred and thirty-four cases of acute radiation syndrome (ARS)
3. Twenty-eight deaths within the first 3 months
4. Two deaths from the initial explosions
5. One death from congestive heart failure

(From Leikin JB, et al. (1) Reprinted with permission from Elsevier)

The two isotopes primarily responsible for the health effects were ^{137}Cs and ^{131}I (radioactive iodine). Given the extent of the accident, the effective response led to relatively few deaths (1). However, the significant widespread environmental contamination necessitated a permanent evacuation of 25,000 people.

Improvised Nuclear Devices and Stolen Nuclear Weapons

Detonation of an improvised or stolen nuclear weapon by terrorists is the worst-case radiological attack scenario (5). Although difficult to construct, due to requirements for sophisticated engineering and expertise, an improvised nuclear device could produce a yield similar to the Hiroshima bomb, with release of radiation, blast, thermal pulses, and radioactive fallout (1). At a minimum, a small nuclear detonation could cause damage equal or exceeding the September 11 attacks in New York City. Even if the nuclear detonation were unsuccessful, the conventional explosion associated with the device could cause significant environmental contamination with the nuclear weapons material, such as plutonium or uranium (1).

The high security associated with storage of nuclear weapons, at least in the western world, makes the probability of stealing a nuclear weapon remote. However, it is possible that 50–100 small nuclear weapons, with a 1 kiloton rating, are unaccounted for in the former Soviet Union (1). Terrorists could fashion these weapons into “suitcase bombs.” If they were to detonate one such weapon, the blast range would reach 400 yards, thermal radiation would extend to the blast distance and nuclear radiation, including gamma particles and neutrons, would reach half a mile (1). If terrorists detonated the device in the air, the resulting electromagnetic pulse could damage solid-state equipment, including solid-state defibrillators, electrocardiograph machines, ventilators and other life-saving equipment. Radioactive fallout could cause high exposures for up to half a mile, requiring sheltering people for at least 2 weeks (1).

Certainly, the technical expertise to develop crude devices, including improvised nuclear devices, exists worldwide (4). Whereas terrorist attacks with SRDs and RDDs would cause a limited number of casualties, attacks with improvised or sophisticated nuclear weapons, if used in a populated area, have the potential for mass casualties and disruption. The Joint Commission on Accreditation of Healthcare Organizations has already directed hospitals to plan and prepare for a terrorist attack involving nuclear weapons, specifically asking them to (2):

- Incorporate contingency planning for loss of infrastructure and personnel
- Develop plans for relocating victims to operational hospitals
- Coordinate activities with appropriate local, state and federal agencies

Radiation Injury: Mechanism of Action

Ionizing radiation is electromagnetic energy or energetic particles emitted from a source (1). Ionizing radiation causes injury by depositing energy in tissue (5). The energy leads to formation of free radicals, which can damage DNA and other cellular structures and processes. The extent of injury and the risk of chronic health effects are proportional to the dose received and the rate of delivery. Cellular repair mechanisms can handle injuries caused by a given dose received slowly. The same dose, received more rapidly, can overwhelm cellular repair mechanisms, leading to

cell death and malignant transformation (5). High exposures, received acutely, can kill some parenchymal cells. If the cells are not critical for survival, the clinical effect may be negligible. However, acute doses that kill large numbers of parenchymal cells or kill cells essential for organ function will cause clinical symptoms. Rapidly dividing cells, such as those of the gastrointestinal mucosa and the bone marrow, are most sensitive. At radiation doses below 100rad (1.0Gy), damage is limited, with most cells surviving, although some of the cells may undergo malignant transformation (5).

Depending on the incident, radioactive material cause radiation exposure in one or more (any combination) of three ways (1,2):

- *External radiation (irradiation)*: because radioactive material is not deposited on or in the body, decontamination is not necessary
- *External contamination*: In this scenario, radioactive material is present on external body surfaces; as with chemical contamination, responders should use caution to avoid contaminating other health care workers and facilities
- *Internal contamination*: Though inhalation, ingestion or transdermal absorption, radioactive material is deposited into body tissues

Types of Ionizing Radiation

There are several types of ionizing radiation, including alpha particles, beta particles, neutrons, gamma rays and X-rays. Alpha particles, containing two protons and two neutrons, contain a large amount of energy but cannot penetrate very far. While alpha particles can travel 2–3 cm in air, they can penetrate only microns into tissue. Clothing and even the outer, dead layers of skin will block alpha particles and prevent them from causing any injury to live tissue. Therefore, external contamination by alpha particles is not hazardous. On the other hand, alpha particles emitted from sources that have entered the body through ingestion, inhalation or wounds can cause significant damage to adjacent live tissue. Alpha particles are therefore a significant internal hazard (1,7). Radioisotopes with atomic numbers of 82 and higher, such as uranium or plutonium, are the major sources of alpha particles (4).

Beta particles are high-energy electrons. Compared to alpha particles, beta particles are less massive, can travel farther, up to 1 m in air, and penetrate deeper, up to a centimeter into exposed skin. A light material, such as aluminum or thick plastic, can block penetration. Clothing, including hospital protective clothing, will only partially block beta particle penetration. Depending on the radioactive isotope source, beta particles can have varying degrees of energy, measured in mega electron volts (MeV). Beta particles containing low levels of energy, 0.1MeV, will penetrate 0.15cm into tissue, whereas those with 5MeV can penetrate 5cm into live tissue. Beta particles left on the skin can cause severe burns to the skin and to the anterior compartment of the eye. Like alpha particles, beta particles are a significant internal hazard (1,4,7).

Neutrons, emitted from nuclear detonations, particle accelerators and nuclear weapon assembly facilities and not found in fallout, can penetrate deeply, causing

extensive damage in two ways, either collision with other particles and/or neutron capture (1,4,7). Several elements, such as sodium, can “capture” neutrons. When exposed to neutron radiation, nonradioactive sodium (^{23}Na) can capture a neutron to become radioactive sodium (^{24}Na). In this way, exposed persons can become radioactive (1).

Gamma rays, high-energy rays with no mass and with short wavelengths, are very penetrating, traveling many meters in air and penetrating many centimeters into tissue. These characteristics make gamma rays capable of causing whole-body exposure (7). Lead, concrete or uranium shielding can markedly attenuate exposure, but cannot completely prevent penetration. These materials are usually not available on short notice, however. Clothing will not protect against gamma radiation, but it can prevent skin contamination by isotopes that emit gamma radiation. X-rays are similar to gamma rays but with a longer wavelength (1).

The human exposure measure for ionizing radiation is the radiation absorbed dose (rad), reflecting the amount of energy the ionizing radiation deposits in the body. The International System skin dose unit for radiation absorbed dose, the gray (Gy) is replacing the rad as a measure. 1 Gy, equivalent to 1 J kg^{-1} is equivalent to 100 rads; 10 mGy is equivalent to 1 rad. These measures are independent of the form or the radiation, and can reflect exposures that are single or multiple, or long or short duration (7). Exposure is proportion to dose and time of exposure, and inversely proportional to the square of the distance from the source (1).

Depending on the dose, dose rate and route of exposure, radiation can cause Acute Radiation Syndrome (ARS), cutaneous injury and scarring, chorioretinal damage (due to exposure to infrared energy), and increased long term risk for cancer, cataract formation (especially due to neutron irradiation), infertility and fetal abnormalities, such as growth retardation, fetal malformations, increased teratogenesis and fetal death (2).

Radiation injury causes two types of effects on biologic symptoms, stochastic and deterministic. Stochastic effects are “all or nothing” effects. At increasing doses, the probability of a stochastic effect increases, but once the stochastic effect occurs, further increases in exposure will not worsen the severity of the effect. A common stochastic effect is radiation-associated malignancy. In comparison, the severity of deterministic effects is proportional to the dose. Examples of deterministic effects include suppression of hematopoiesis, cataract formation and fertility impairment (4).

Nonradiation Hazards from Improvised Nuclear Devices and Nuclear Detonations

In addition to radiation exposure, and depending on the distance from the detonation, a nuclear explosion can expose people to two other types of energy, heat and blast. Heat accounts for approximately 35% of the energy released in a nuclear detonation. The bomb blast, or shock, accounts for approximately another 50%. Radiation energy accounts for only 15% of the energy from the detonation (2).

Heat and light cause thermal injuries, such as flash burns, flame burns and retinal burns. Temporary depletion of photopigment from the retinal receptors causes flash blindness. The blast wave causes physical injuries, such as fractures, lacerations, visceral ruptures, pulmonary hemorrhage and edema.

Radiation Injury: Clinical Presentation

Acute Radiation Syndrome

ARS, also known as radiation sickness, occurs after whole-body or significant partial-body exposure to more than 1 Gy at a relatively high dose rate (2). To cause ARS, the exposure must meet the following conditions (8):

- The absorbed dose must be large, generally greater than 0.7 Gy (70 rad), although patients may have mild symptoms at doses as low as 0.3 Gy (30 rad).
- The dose usually must be external. Ingested or inhaled radioactive materials have rarely caused ARS.
- The radiation must be penetrating, involving X-rays, gamma rays or neutrons.
- The whole body, or a significant portion of the body, must receive the dose. The most frequent radiological accidents cause local injury, frequently the hands, and do not cause ARS.
- The dose rate must be rapid, with the dose usually received within minutes. Doses split into fractions and delivered intermittently rarely cause ARS, compared to the same dose delivered at one time.

The most replicative cells, particularly spermatocytes, lymphohematopoietic cells and intestinal crypt cells are the most sensitive to the effects of ionizing radiation. The resulting clinical picture reflects damage to these cellular elements, and includes hematopoietic, gastrointestinal, cerebrovascular and cutaneous component syndromes. Each syndrome consists of four phases, prodromal, latent, manifest illness, and recovery or death. The time course and severity of the syndromes reflect the degree and rate of exposure (2). Table 4.1 illustrates the first three phases, including onset time, associated signs and symptoms, affected organ systems and prognosis (7).

Depending on the absorbed dose, patients will progress through the four phases at different rates, following a predictable clinical course. The prodromal phase usually begins within 48 h, but can occur as late as 6 days following exposure. Clinicians can estimate the dose a patient may have absorbed based on symptoms, system onset and laboratory studies. The presence and onset time of nausea and vomiting and the results of serial CBCs can help clinicians determine the severity of exposure. For example, significant lymphocytopenia developing in the first 6–48 h is a reliable indication that a patient will require prolonged, intense observation and treatment (5).

Table 4.1 Acute radiation syndrome

Phase	Feature	Dose range					
		0–100	100–200	200–600	600–800	800–3,000	>3,000
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	No effect	Minimal decrease	<1,000 at 24 h	<500 at 24 h	Decreases within hours	Decreases within hours
Latent	CNS function	No effect	No effect	Routine task performance cognitive impairment for 6–20 h	Simple, routine task performance cognitive impairment for >24 h	Rapid incapacitation	
	Manifest illness	No symptoms	7–15 days	0–7 days	0–2 days	May have a lucid interval of several hours	None
Manifest illness	Signs, symptoms	>2 weeks	Moderate leukopenia		Severe leukopenia, purpura, hemorrhage, pneumonia, hair loss after 300 rad	Diarrhea, fever, electrolyte imbalance	Convulsions, ataxia, tremor, lethargy
	Time of onset		>2 week	2 days–2 weeks	2 days–2 weeks	2–14 days	1–3 days
	Critical period		None	4–6 weeks; greatest potential for effective medical intervention			1–48 h

(continued)

During the relatively brief latent phase, prodromal symptoms improve, and patients may appear recovered. Although patients may be asymptomatic, rapidly proliferating hematopoietic and gastrointestinal cells continue to die during the latent phase. The duration of the latent phase varies, depending on the radiation dose absorbed, the presence of any coexisting illness or injury and other patient characteristics (4). The manifest illness phase, characterized by moderate to severe immunosuppression, soon follows, with symptoms lasting up to weeks, depending on the absorbed dose. Clinical manifestations depend on several factors, including the organ system most involved (hematopoietic, gastrointestinal, vascular, neurological and cutaneous), the absorbed dose, and any associated coexisting illnesses or injuries (4).

Supralethal absorbed doses cause an accelerated progression, with patients experiencing all phases within hours rather than weeks, with death following within 2–12 days, depending on the dose (2). Radiation victims with associated physical trauma from blast effects are likely to have higher morbidity and mortality compared to uninjured patients, due to increased likelihood of complications such as hemorrhage, sepsis and delayed wound healing (4). Patients surviving the manifest illness phase enter the recovery phase, which can last from weeks to months.

Table 4.2 illustrates the four distinct syndromes involving the hematopoietic, gastrointestinal and cerebrovascular systems.

The Hematopoietic Syndrome

The hematopoietic syndrome results from whole body irradiation sufficient to suppress the production and function of formed blood elements. Although some bone marrow suppression can occur with doses as low as 0.7 Gy, the syndrome is seldom associated with absorbed doses less than 1 Gy (100 rads). Doses greater than 2–3 Gy suppress the ability for hematopoietic progenitor cells to divide. White blood cells, especially lymphocytes, are particularly sensitive to radiation injury. Depending on the absorbed dose, within weeks after exposure, patients can develop a hematologic crisis, with bone marrow hypoplasia or aplasia. Maximum bone marrow suppression generally occurs 2–4 weeks after exposure. Patients can develop pancytopenia, predisposing them to infection, particularly with Gram-negative bacteria. In addition to infection, hemorrhage and poor wound healing can also contribute to death (2,4,5).

Lymphocytopenia commonly occurs and tends to develop before other cytopenias (2). The predictability of lymphocytopenia following radiation exposure makes it somewhat useful as a prognostic indicator. An absolute lymphocyte count drop of 50% within the first 24h after exposure, followed by a more severe decline over the ensuing 48h, is characteristic of a lethal exposure (2). Some investigators have developed models using lymphocyte counts as measures of radiation exposure. However, associated injuries, such as burns and trauma, can also cause lymphocytopenia. Although some studies have validated the lymphocyte count predictive models, including models that account for coexisting injuries, clinicians should not rely solely on lymphocyte counts in establishing a prognosis or estimating absorbed dose (2).

Table 4.2 Syndromes associated with acute radiation exposure

Syndrome/Dose	Phase			Recovery or death
	Prodrome	Latent	Manifest illness	
Hematopoietic >0.7 Gy (> 70rads) (mild symptoms may occur as low as 0.3Gy or 30rads)	Lymphocytopenia Symptoms are anorexia, nausea and vomiting. Onset occurs 1 h to 2 days after exposure. Stage lasts for minutes to days	Although patients may be asymptomatic, rapidly proliferating cells continue to die; stage lasts 1–6 weeks	Symptoms are anorexia, fever and malaise Drop in all blood cell counts for several weeks; survival decreases with increasing dose; most deaths occur within a few months after exposure	In most cases, bone marrow cells begin to replicate; full recovery for a large % of individuals from a few weeks up to 2 years after exposure. Death may occur in some patients at 1.2 Gy (120rads); the LD _{50/60} ^a is about 2.5–5 Gy (250–500rads). Sepsis and hemorrhage are primary causes of death
Gastrointestinal >10 Gy (>1,000 rads) (some symptoms may occur as low as 6Gy or 600rads)	Abdominal pain, anorexia, nausea, vomiting and diarrhea. Onset occurs within a few hours after exposure; stage lasts about 2 days	Although patients may be asymptomatic, rapidly proliferating cells continue to die; stage lasts less than 1 week	Malaise, abdominal pain, nausea, vomiting, severe diarrhea, high fever, dehydration, electrolyte imbalance, gastrointestinal hemorrhage, anemia cardiovascular collapse, malnutrition, bowel obstruction, sepsis, renal failure	At doses greater than 12 Gy, mortality rate exceeds that of hematopoietic syndrome; death due to infection, dehydration and electrolyte imbalance within 2 weeks of exposure; the LD ₁₀₀ ^b is about 10 Gy (1,000rads)

<p>Cerebrovascular >50 Gy (5,000 rads) (some symptoms may occur as low as 20 Gy or 2000 rads)</p>	<p>Nausea, vomiting, watery diarrhea, burning sensation of skin, disorientation, fever, extreme nervousness, confusion, impairment of cognitive function prostration, hypotension, ataxia and convulsions; onset within minutes of exposure; stage lasts for minutes to hours</p>	<p>Lucid period up to 5–6 h; patient may return to partial functionality</p>	<p>Watery diarrhea, convulsions, coma, respiratory distress, high fever, and cardiovascular collapse; differential diagnosis to consider is sepsis and septic shock; day</p>	<p>Death from cardiovascular collapse, cerebral edema, increased intracranial pressure and cerebral anoxia within 3 days in severe exposure. No recovery expected.</p>
--	---	--	--	--

Adapted from <http://www.bt.cdc.gov/radiation/arsphysicianfactsheet.asp>, last accessed 9-11-05

^a*LD*_{50/60} dose necessary to kill 50% of the exposed population in 60 days

^b*LD*₁₀₀ dose necessary to kill 100% of the exposed population

Other cytopenias develop later depending on the absorbed dose and dose rate. After exposures less than 5 Gy, granulocyte counts may transiently increase before decreasing (2). The increase, known as an abortive rise, may be a prognostic indicator of a survivable exposure (2). Coexisting physical trauma and burns resulting from improvised nuclear devices complicate the treatment of patients with hematopoietic syndrome, and increase the mortality rate (2).

The Gastrointestinal Syndrome

As radiation exposure increases, patients are more likely to develop the gastrointestinal syndrome. Radiation doses greater than 5 Gy can destroy intestinal mucosal stem cells, resulting in loss of intestinal crypts and interruption of the intestinal mucosal barrier. Within hours after exposure, patients experience a rapid onset of gastrointestinal symptoms including abdominal pain, nausea, vomiting and diarrhea. Depending on the exposure, these symptoms can continue for 1–2 days, followed by a symptom-free latent period lasting up to a week. The recurrence of gastrointestinal symptoms, including vomiting, severe diarrhea and high fever, signals the end of the latent period. Systemic complications include electrolyte imbalance, dehydration, malabsorption with concomitant malnutrition, ileus resulting in bowel obstruction, gastrointestinal hemorrhage resulting in anemia, sepsis, acute renal failure and cardiovascular collapse (2,5). Beyond exposure doses of 12 Gy, the mortality rate from the gastrointestinal syndrome exceeds the mortality rate of the hematopoietic syndrome (2).

The Cerebrovascular Syndrome

Whole-body, ionizing radiation doses greater than or equal to 20–30 Gy (2,000–3,000 rad), cause hypotension and cerebral edema, contributing to the cerebrovascular syndrome. The prodromal phase, beginning almost immediately after exposure, includes nausea, vomiting, disorientation, confusion, prostration, hypotension, ataxia and convulsions. Patients presenting with fever, hypotension and major impairment of cognitive function have most likely experienced a supralethal dose of radiation, and are likely to die within several days. Physical examination may reveal papilledema, ataxia, and reduced or absent deep tendon and corneal reflexes. Patients may experience a latent, lucid period of up to several hours. Soon after, watery diarrhea, respiratory distress, hyperpyrexia and cardiovascular collapse follow. The differential diagnosis, which clinicians should consider, includes acute sepsis and septic shock. Within 2 days, patients are likely to die from circulatory complications of hypotension, cerebral edema, increased intracranial pressure and cerebral anoxia. Fortunately, events sufficient to cause this degree of exposure have rarely occurred, affecting only a few accident victims worldwide (5).

The Cutaneous Syndrome

Some skin damage frequently accompanies ARS. However, the cutaneous syndrome can also result from localized acute radiation exposure to the skin, usually from direct handling of radioactive sources or from contamination of the skin or clothes (2,8) (see Figs. 4.1 and 4.2) With localized exposure, even with high doses, the victim frequently survives, because the whole body usually does not receive the localized dose. However, if a patient with localized radiation induced cutaneous injury has also received whole body irradiation from an external source, the cutaneous damage increases the risk for death from the whole body exposure (2). Patients with the hematopoietic syndrome due to whole body irradiation will recover more slowly, if at all, from cutaneous injury due to bleeding, infection and poor wound healing (2).

Radiation damage to the basal cell layer can lead to inflammation, erythema and dry or moist desquamation. In addition, radiation can damage hair follicles, causing epilation. Within a few hours after exposure, exposed patients may develop a transient and inconsistent erythema associated with itching. These symptoms resolve, followed by a latent phase of more than a week. 12–20 days after exposure, patients present with intense erythema and desquamation or blistering. Ulceration may also be visible (5,8). Epidermal and sometimes, dermal loss characterizes the cutaneous injury from radiation exposure. Although the skin injury may cover a small area, the damage may extend deeply into soft tissue, affecting muscle and bone. Patients may develop significant local edema with the potential for a compartment syndrome (2).

Compared to thermal burns, radiation induced burns develop more than a week after exposure. Therefore, patients presenting with burn injuries immediately after exposure are suffering from thermal rather than radiation burns. Table 4.3 illustrates the relationship between exposure dose and cutaneous injury.

Radiation Injury: Diagnosis, Triage and Exposure Assessment

The diagnosis of ARS, especially after an unannounced attack with a SRD, may be difficult, because ARS does not appear as a unique disease. Like biologic agent exposures, radiation exposure may not have an immediate impact due to the interval between exposure and the onset of symptoms. Consequently, the most likely responders to future radiological attacks may be family physicians and other primary health care providers. For example, after exposure to a SRD, some exposed patients would arrive at their doctors' offices and local emergency rooms several days later, while others may have traveled, showing up at emergency rooms distant from their homes. Their prodromal symptoms might appear at first to be an ordinary gastrointestinal illness, with abdominal pain, nausea, vomiting and diarrhea. Following the prodrome, the exposed patients would enter the latent phase, feeling well and recovered from what appeared to be a brief gastrointestinal illness.

In the past, radiation accidents have frequently resulted in a delayed diagnosis. In a study of four radiation accidents due to lost sources (Mit Halfa, Egypt, May 2000,



Fig. 4.1 (See color Plate) Acute ulceration in a Peruvian patient who inadvertently placed a 26-Ci ^{192}Ir source in his back pocket, 3 days postexposure. The source remained in the pocket for approximately 6.5 h (From the medical basis for radiation accident preparedness, proceedings of the fourth international conference on accident preparedness, March 2001. Reproduced with permission of Routledge/Taylor & Francis Group, LLC. Also available at: <http://www.bt.cdc.gov/radiation/crphysicianfactsheet.asp#B>.)



Fig. 4.2 (See color Plate) Same patient, 10 days postexposure (from the medical basis for radiation accident preparedness, proceedings of the fourth international conference on accident preparedness, March 2001). Reproduced with permission of Routledge/Taylor & Francis Group, LLC. Also available at: (<http://www.bt.cdc.gov/radiation/crphysicianfactsheet.asp#B>, last accessed 5-11-06)

Bangkok, Thailand, February 2000, Tammiku, Estonia, October 1994 and Goiania, Brazil, September 1987) a mean 22 days elapsed between exposure and diagnosis (5).

Nevertheless, astute clinicians can make a correct diagnosis by taking a thorough medical history. Clinicians should consider ARS in any patient with nausea and vomiting unexplained by other causes. Additional evidence pointing toward ARS includes bleeding, epilation, or white blood cell and platelet counts abnormally low a few days or weeks after any unexplained nausea and vomiting (8).

Because terrorists are unlikely to announce an attack with a simple radiological device or a RDD, there may be no warning that contaminated patients are arriving at an

Table 4.3 Cutaneous radiation injury

Grade	Skin dose ^a	Prodromal stage	Latent stage ^b	Manifest illness stage	Third wave of erythema ^c	Recovery	Late effects
I	>2 Gy (200 rads)	1–2 days postexposure or not seen	No injury evident for 2–5 weeks postexposure ^b	2–5 weeks postexposure, lasting 20–30 days; redness of skin, slight edema, possible increased pigmentation	Not seen	Complete healing expected 28–40 days after dry desquamation (3–6 months postexposure)	Possible slight skin atrophy Possible skin cancer decades after exposure
II	>15 Gy (1500 rads)	6–24 h postexposure with immediate sensation of heat lasting 1–2 days	No injury evident for 1–3 weeks postexposure	1–3 weeks postexposure; redness of skin, sense of heat, edema, skin may turn brown	10–16 weeks postexposure, injury of blood vessels, edema, and increasing pain	Healing depends on size of injury and the possibility of more cycles of erythema	Possible skin atrophy or ulcer recurrence Possible telangiectasia (up to 10 years postexposure) Possible skin cancer decades after exposure
				5–6 weeks postexposure, edema of subcutaneous tissues and blisters with moist desquamation Possible epithelialization later	Epilation may subside, but new ulcers and necrotic changes are possible		

III	>40Gy (4000 rads)	4-24h postex- posure, with immediate pain or tin- gling lasting 1-2 days	None or less than 2 weeks	1-2 weeks post- exposure; red- ness of skin, blisters, sense of heat, slight edema, "possible" increased pigmentation	10-16 weeks postexposure: injury of blood vessels, edema, new ulcers, and increasing pain	Can involve ulcers that are extremely difficult to treat and that can require months to years to heal fully	Possible skin atrophy, de- pigmentation, constant ulcer recurrence, or deformity Possible occlu- sion of small vessels with subsequent disturbances in the blood sup- ply, destruc- tion of the lymphatic net- work, regional lymphostasis, and increasing fibrosis and sclerosis of the connective tissue Possible telangi- ectasia Possible skin cancer decades after exposure
-----	----------------------	---	------------------------------	---	--	---	--

(continued)

Table 4.3 (continued)

Grade	Skin dose	Prodromal stage	Latent stage	Manifest illness stage	Third wave of erythema	Recovery	Late effects
IV	>550 Gy (55,000 rads)	Occurs minutes to hours postexposure, with immediate pain or tingling, accompanied by swelling	None	1–4 days post-exposure accompanied by blisters Early ischemia (tissue turns white, then dark blue or black with substantial pain) in most severe cases Tissue becomes necrotic within 2 weeks following exposure, accompanied by substantial pain	Does not occur due to necrosis of skin in the affected area	Recovery possible following amputation of severely affected areas and possible skin grafts	Continued plastic surgery may be required over several years Possible skin cancer decades after exposure

Source: Centers for Disease Control and Prevention, Cutaneous Radiation Injury: Fact Sheet for Physicians. June 29, 2005 <http://www.bt.cdc.gov/radiation/criphysicianfactsheet.asp>

^aAbsorbed dose to at least 10 cm² of the basal cell layer of the skin

^bSkin of the face, chest, and neck will have a shorter latent phase than the skin of the palms of the hands and the skin of the feet

^cEspecially with beta exposure

emergency room or office (1). Therefore, responders may not be aware of the existence, source of contamination or dose absorbed. Once clinicians suspect ARS, if possible, they should document the specific source, and the time of onset and severity of symptoms.

Triage

Appropriate triage is essential for evaluating and sorting out individuals who may need immediate treatment. Once health care responders suspect radiation exposure, they should (2,5,8):

- Provide first aid and resuscitation, including securing ABCs (airway, breathing and circulation) and beginning physiologic monitoring, such as vital signs, blood gases, electrolytes and urine output as appropriate.
- Minimize external radiation to rescue and treatment personnel. The Oak Ridge Associated Universities Website (<http://www.ora.gov/reacts/care.htm#Techniques>, last accessed 5–11–06) contains detailed guidelines for protection of health care and rescue personnel (9). Strict isolation precautions, including gowns, masks, caps, double gloves and shoe covers are required when evaluating and treating contaminated patients. In addition, staff should change gloves frequently to avoid cross contaminating other patients and staff. Staff should use appropriate radiation detection devices to detect contaminants in the hospital to facilitate removal and decontamination. After use, health care staff should remove their protective equipment, placing the equipment in clearly labeled, sealed containers. All health care workers who have adhered to the Oak Ridge guidelines have avoided contamination from handling radiation accident victims (2).
- Stabilize the patient, medically and surgically, and provide definitive treatment of serious injuries, including major trauma, burns and respiratory injury if evident. Patients should receive necessary surgical interventions within 36 h and no later than 48 h after exposure; surgery after that time is contraindicated for 6 weeks or until evidence appears that the patient is immunocompetent and that incised tissue is capable of revascularizing (10).
- Besides obtaining blood samples to address trauma, obtain blood samples for complete blood counts helpful in estimating exposure dose, paying particular attention to the lymphocyte count and human leukocyte antigen typing before any initial transfusion.
- Assess the patient for contamination and decontaminate as necessary.

External Decontamination

Fortunately, skin or wound contamination rarely presents a life-threatening risk to either patients or health care personnel (5). The best possible scenario is decontamination in the field before transport; however, following an attack with a radiologic dispersion device (RDD), patients suffering trauma will most likely present to emergency departments before undergoing external contamination.

The first step in external decontamination is removal of outer clothing and shoes, which should reduce the level of contamination by 90% (5). A radiation detector, held at a constant distance from the skin and passed over the entire body, is useful in assessing any residual external contamination. Following the assessment, washing the skin and hair with soap and warm water, along with gentle brushing to remove contaminated particles is effective in removing any residual contamination. Health care responders should take care to avoid damaging the skin during the decontamination process. In addition, covering open wounds can help prevent additional internal contamination. Following the first attempt at decontamination, responders should repeat the assessment process with the radiation detector, at the same distance from the skin as they did initially. If any residual contamination is still present, response staff should repeat hair and skin washing and brushing and reassess with the radiation detector. The ultimate decontamination goal is to reduce the level of external contamination below two times the background radiation level, or until the repeated attempts fail to reduce the level by 10% or more (5).

Cleaning wounds to remove contamination is essential, because wounds promote internal contamination through absorption of radioactive materials directly into the circulatory and lymphatic systems (5). The technique used depends on the nature of each wound. Standard decontamination techniques, such as irrigation, are effective against abrasions. However, lacerations and puncture wounds can present challenges due to poor access to the contaminants. If irrigation is ineffective, some lacerations may require excision of contaminated tissue. Likewise, puncture wounds may be difficult to decontaminate with oral irrigators or water jets, although irrigation is worth trying. Wounds containing radioactive shrapnel are particularly problematic and require special care. Amputation has been necessary when removal of radioactive shrapnel from heavily contaminated extremities was unsuccessful (5).

Biodosimetry

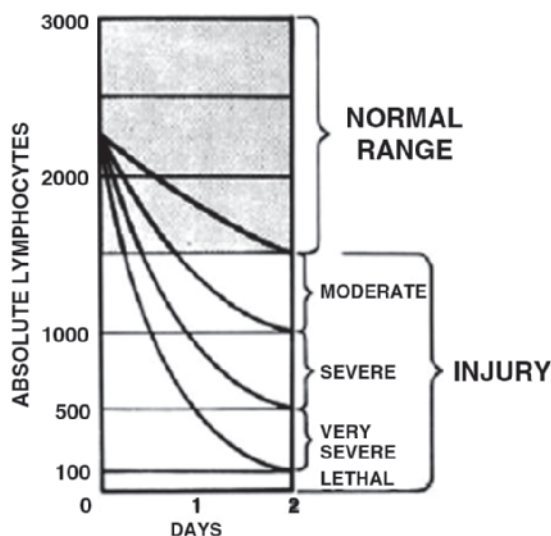
After stabilization and external decontamination, patients require assessment for radiation injury based on dose, specific isotope involved and the presence of internal contamination. By performing individual biodosimetry, physicians can predict the subsequent clinical severity, survivability and treatment required, as well as triage patients with subclinical or no exposure (2). The three most useful items for estimating exposure doses in a mass casualty situation are:

- Time from exposure to onset of emesis
- Lymphocyte depletion kinetics
- Presence of chromosome dicentric

Clinicians can crudely estimate the absorbed dose from the clinical presentation and peripheral leukocyte counts. The interval from exposure to emesis onset decreases with increasing doses. If the interval is less than 4h, the effective whole body dose is probably at least 3.5Gy. If the interval is under 1h, the patient probably received a dose of 6.5Gy or more. Patients with this level or exposure are likely to experience a complicated medical course with a high fatality rate (5).

Lymphocytes are the most radiosensitive of all blood elements, and their count numbers decline following first-order kinetics after high-level total body exposure (5,10). The rate of decline is related linearly to the total body exposure dose, making lymphocyte count monitoring particularly helpful in dose estimation (11). Patients presenting within 8–12 h of exposure should have complete blood counts with leukocyte differential immediately after exposure, repeated every 2–3 h during the first 8 h after exposure, repeated every 4–6 h during the ensuing 2 days, and repeated twice per day for the following 3–6 days to monitor declines in lymphocyte counts (2,8). At a minimum, to estimate exposure dose, patients should have three (preferably six) blood counts with differential obtained within the first 4 days after exposure to calculate a slope for lymphocyte count decline (2). Figure 4.3, the Andrews Lymphocyte Nomogram, illustrates the relationship between the rate of lymphocyte depletion and the severity of injury (8).

If available, a qualified cytogenic laboratory can help estimate exposure dose by analyzing chromosome aberrations in peripheral blood lymphocytes. After exposure, lymphocytes can display several types of chromosome aberrations. Dicentric, chromosomes with two centromeres, are biomarkers for exposure to ionizing radiation (7). Clinicians interested in evaluating chromosome dicentrics should request 10 mL of peripheral blood drawn 24 h after exposure, placing the sample in a lithium-heparin tube or an ethylenediaminetetraacetate (EDTA) tube (2,7). During transport to the lab, the samples require a cold pack to remain at 4°C, but not frozen. The laboratory will isolate the blood lymphocytes, stimulate them to grow in culture, arrest cell proliferation during the first metaphase, and observe metaphase



From Andrews GA, Auxier JA, Lushbaugh CC. *The Importance of Dosimetry to the Medical Management of Persons Exposed to High Levels of Radiation. In Personal Dosimetry for Radiation Accidents.* Vienna: International Atomic Energy Agency; 1965.

Fig. 4.3 Andrews lymphocyte nomogram (reprinted with permission)

spreads microscopically for enumeration of dicentric. Using an established dose response curve, the laboratory will report the estimated dose the exposed patient received (7). Because of the necessary incubation times, results will not be available for 48–72 h after sample submission (2).

The Armed Forces Radiobiology Research Institute Web site (<http://www.afrii.usuhs.mil>, (2,7) last accessed 1–01–06) features a radiation casualty management software program, the biological assessment tool (BAT), that clinicians can use to estimate exposure dose (12). The software archives clinical information, including the extent of contamination, the presence of wounds and infection, and displays the diagnostic information in a concise format. The software includes an interactive map of the human body that allows users to document the location of a personnel dosimeter, radiation-induced erythema and radioactivity detected with an appropriate detection device. The Institute is also developing triage software for palm devices that will allow first responders to triage suspected radiation casualties based on initial, prodromal features.

Whether or not the BAT is available, using medical cards or flow charts, clinicians caring for exposed patients should document prodromal signs and symptoms as a function of time after exposure throughout the course of management (2). Documentation should include the body location of radioactivity, thermal and traumatic injuries, the degree of erythema and lymphocyte counts. Health care staff can enter these data into BAT or alternative tools at triage stations to facilitate estimation of exposure doses and appropriate triage.

Physicians caring for pregnant women exposed to radiation should attempt to estimate the fetal exposure. Although the uterus provides some protection, the human embryo and fetus are more sensitive to radiation exposure than adults are, and the health consequences for the fetus may be severe at doses too low to immediately affect the mother. Such health consequences can include growth retardation, malformations, impaired brain function and cancer (13).

Fetal exposure is a function of the external and internal maternal exposure. The external dose to the mother's abdomen provides a reasonable estimation of the external exposure to the fetus. Estimating the internal fetal dose is more complex. Any contaminant ingested or absorbed by the mother eventually entering the maternal blood stream may pass through the placenta to the fetus. Although the placenta provides some protection, most contaminants reaching the maternal circulation are detectable in the fetal circulation. Fetal concentrations depend on the specific contaminant and the stage of fetal development. For example, substances such as iodine, needed for fetal growth and development, reach higher concentrations in the fetus compared to the mother. In addition, any radioactive material that concentrates in the maternal tissues adjacent to the uterus, such as the bladder, can cause fetal exposure. Internal exposures to substances tending to concentrate in specific organs, such as iodine-131 and iodine-123 in the thyroid, iron-59 in the liver, gallium-67 in the spleen and strontium-90 and yttrium-90 in the bones, can cause exposure to their corresponding fetal organs.

Physicians can obtain assistance in estimating fetal dosages. Hospital health and medical physicists may be available to help. The National Council on Radiation

Protection and Measurements (NCRP) Report Number 28, Radionuclide Exposure of the Embryo/Fetus contains information useful for estimating fetal exposures. The report, available at <http://www.ncrponline.org/ncrprpts.html> (last accessed 1–29–06) contains fetal radiation dose estimates for 83 radionuclides (14). The report also contains information the mechanisms and consequences of prenatal radiation exposure.

Clinicians seeking additional help with fetal dose estimation can locate their state Radiation Control/Radiation Protection Contact through the Conference of Radiation Control Program Directors, Inc. (CRCPD) Web site at <http://www.crcpd.org/map/map.asp> (last accessed 1–29–06). In addition, the Health Physics Society (HPS) Web site contains a list of certified Health Physicists at <http://www.hps1.org/aahp/members/members.htm> (last accessed 1–29–06) who can help with fetal dose estimation.

After estimating fetal exposure, clinicians should consider the potential health effects on the fetus. Potential fetal health effects other than cancer are a function of gestational age and radiation dose (13). The information in Table 4.4 can help physicians advise their pregnant patients, but the table does not provide definitive recommendations. However, clinicians should consider these basic principles in providing advice to pregnant women exposed to radiation:

- The main health concern for significant exposures greater than 0.1 Gy early in the pregnancy (before 2 weeks of gestation) is death of the embryo. If the embryo survives the exposure, noncancer health consequences are unlikely, no matter how high the exposure dose. The reason for this is that the few cells contained in the embryo are progenitors for many other cells. Damage to one cell in the embryo will generally cause the death of the embryo. Surviving embryos successfully implanting in the uterus are unlikely to exhibit congenital abnormalities (13).
- Throughout gestation, radiation-induced noncancer health effects are undetectable for fetal doses below 0.05 Gy. Available research suggests that doses below 0.05 Gy represent no risk at any stage of development. However, research on rodents suggests that doses in the 0.05–0.10 Gy range may present a small risk of malformations or central nervous system abnormalities at some stages of gestation. Nevertheless, when providing advice regarding prenatal exposure, clinicians can consider 0.10–0.20 Gy as a practical threshold for congenital effects in the human embryo or fetus (13).
- Between 8 and 15 weeks of gestation, radiation can impair brain development, with atomic bomb survivor data revealing an average IQ loss of 25–31 points per Gy above 0.10 Gy. The risk for severe mental retardation increases by 40% per Gy at doses above 0.10 Gy (13).
- Between approximately 16 weeks gestation and birth, radiation-induced noncancer health effects are unlikely for fetal exposures below 0.50 Gy. Although some researchers believe that doses above 0.10 Gy between 16 and 25 weeks of gestation present a small risk for impaired brain function, most researchers believe that following 16 weeks gestation, 0.50–0.70 Gy doses represent the threshold for congenital effects (13).

Table 4.4 Potential health effects, other than cancer, of prenatal radiation exposure

	Time postconception		
	Blastogenesis (up to 2 weeks) (2–7 weeks)	Organogenesis (8–15 weeks)	Fetogenesis (16–25 weeks) (26–38 weeks)
Acute radiation dose ^a to the embryo/fetus			
<0.05 Gy (5 rads) ^b	Noncancer health effects NOT detectable		
0.05–0.50 Gy (5–50 rads)	Incidence of failure to implant may increase slightly, but surviving embryos will probably have no significant (noncancer) health effects	Incidence of major malformations may increase slightly Growth retardation possible	Noncancer health effects unlikely Noncancer health effects unlikely
>0.50 Gy (50 rads)	Incidence of failure to implant will likely be large, ^c depending on dose, but surviving embryos will probably have no significant (noncancer) health effects	Growth retardation possible Reduction in IQ possible (up to 15 points, depending on dose) Incidence of severe mental retardation up to 20%, depending on dose	Incidence of miscarriage probably will increase, depending on dose Incidence of miscarriage may increase, depending on dose Incidence of miscarriage and neonatal death will probably increase depending on dose ^d
The expectant mother may be experiencing ARS in this range, depending on her whole-body dose			

Substantial risk of major malformations such as neurological and motor deficiencies	Growth retardation likely	Growth retardation possible, depending on dose
Growth retardation likely	Reduction in IQ possible (>15 points, depending on dose)	Reduction in IQ possible, depending on dose
	Incidence of severe mental retardation >20%, depending on dose	Severe mental retardation possible, depending on dose
	Incidence of major malformations will probably increase	Incidence of major malformations may increase

Source: Centers for Disease Control and Prevention. Prenatal Radiation Exposure: A Fact Sheet for Physicians, March 23, 2005. <http://www.bt.cdc.gov/radiation/pdf/prenatalphysician.pdf>

Note: This table is intended only as a guide. The indicated doses and times postconception are approximations.

^aAcute dose: dose delivered in a short time (usually minutes). Fractionated or chronic doses: doses delivered over time. For fractionated or chronic doses the health effects to the fetus may differ from what is depicted here

^bBoth the gray (Gy) and the rad are units of absorbed dose and reflect the amount of energy deposited into a mass of tissue (1 Gy = 100 rads). In this document, the absorbed dose is that dose received by the entire fetus (whole-body fetal dose). The referenced absorbed dose levels in this document are assumed to be from beta, gamma, or X-radiation. Neutron or proton radiation produces many of the health effects described herein at lower absorbed dose levels

^cA fetal dose of 1 Gy (100 rads) will likely kill 50% of the embryos. The dose necessary to kill 100% of human embryos or fetuses before 18 weeks' gestation is about 5 Gy (500 rads)

^dFor adults, the LD50/60 (the dose necessary to kill 50% of the exposed population in 60 days) is about 3–5 Gy (300–500 rads) and the LD100 (the dose necessary to kill 100% of the exposed population) is around 10 Gy (1,000 rads)

- Although the central nervous system is less sensitive to radiation between 16 and 25 weeks gestation, higher doses at this stage can cause similar central nervous system impairment as do lower doses between 8 and 15 weeks. At doses above 0.70 Gy, the average IQ loss is about 13–21 points per Gy. In addition, above 0.70 Gy, the risk for severe mental retardation is about 9% per Gy (13).
- At 16–25 weeks, the fetal thyroid is active and susceptible to damage from radioactive iodine exposure. Maternal exposures will concentrate in the fetal thyroid at this stage of development (13).
- At 26 weeks and beyond, the fetus is less sensitive to noncancer effects from radiation exposure. However, large doses, above 1 Gy increase the risk for miscarriage, fetal death and neonatal death (13).
- In sufficient dosage, ionizing radiation can impair development occurring at the time of exposure. Data for pregnant atomic bomb survivors demonstrate permanent physical growth retardation at increasing exposures, especially above 1 Gy, and especially if the exposure occurs in the first trimester. The survivor data suggest a 3–4% reduction of height at age 18 for exposures greater than 1 Gy (13).

Table 4.5 describes the risk for childhood cancer from prenatal exposure and the lifetime cancer risk for exposure at age 10. Researchers do not know whether the carcinogenic effects of a given radiological exposure vary with gestation. The current wisdom is that carcinogenic effects are constant throughout pregnancy. However, available animal data suggest that exposure during the early stages of pregnancy, during blastogenesis and organogenesis, is less likely carcinogenic. The same data suggest that late in gestation, fetuses are strongly sensitive to carcinogenic effects of ionizing radiation (13).

Also unknown is the lifetime cancer risk following prenatal exposure to radiation. When advising pregnant women exposed to radiation, clinicians should consider that available data suggest that lifetime cancer risk from prenatal exposure is similar to, or slightly higher than, the cancer risk secondary to childhood exposure (Table 4.5).

Internal Decontamination

Clinicians suspecting internal contamination should request samples of urine, stool, vomit and wound secretions to determine the specific contaminant. Patients admitted with airways or endotracheal tubes are more likely to have internal contamination (9). Treatment of ingestion exposures with aluminum hydroxide or magnesium carbonate antacids can prevent or at least minimize internal contamination by reducing gastrointestinal absorption. Following ingestion of strontium isotopes, patients should receive aluminum-containing antacids. Gastric lavage administered within 1–2 h after ingestion can also help reduce internal contamination. Patients suffering from large ingestion doses should receive cathartics, including enemas, to decrease gastrointestinal transit time (5). For patients with significant inhalation exposures to insoluble radionuclides, pulmonary lavage may be considered but is seldom indicated (5).

Table 4.5 Estimated risk for cancer from prenatal radiation exposure

Radiation dose	Estimated childhood cancer incidence ^{a,b} (%)	Estimated ^c lifetime cancer incidence ^d (exposure at age 10) (%)
No radiation exposure above background	0.3	38
0.00–0.05 Gy (0–5 rads)	0.3–1	38–40
0.05–0.50 Gy (5–50 rads)	1–6	40–55
>0.50 Gy (50 rads)	>6	>55

From Centers for Disease Control and Prevention. Prenatal Radiation Exposure: A Fact Sheet for Physicians, March 23, 2005. <http://www.bt.cdc.gov/radiation/pdf/prenatalphysician.pdf>.

^aData published by the International Commission on Radiation Protection

^bChildhood cancer mortality is roughly half of childhood cancer incidence

^cThe *lifetime cancer* risks from prenatal radiation exposure are not yet known. The lifetime risk estimates given are for Japanese males exposed at age 10 years from models published by the United Nations Scientific Committee on the Effects of Atomic males exposed at age 10 years from models published by the United Nations Scientific Committee on the Effects of Atomic Radiation

^dLifetime cancer mortality is roughly one-third of lifetime cancer incidence

Although potassium iodide does not protect the thyroid from external radiation, patients suffering from internal radioiodine contamination should receive potassium iodide to prevent or reduce thyroid uptake. To be effective, patients must receive the potassium iodide within a few hours after exposure (5,11). Compared to adults, children are more susceptible to the effects of radioiodine. Consequently, the Federal Drug Administration (15) and World Health Organization recommendations for administration of potassium iodide differ for children and adults. Table 4.6 contains the FDA recommendations for potassium iodide administration.

Adults older than 40 should receive potassium iodide only if the projected thyroid exposure is 5 Gy or greater. On the other hand, exposed neonates, infants and children should receive potassium iodide to avoid thyroid exposures as low as 10 mGy. Exposed pregnant women should receive potassium iodide to protect themselves as well as their fetus. Administration of potassium iodide to lactating women can reduce the level of radioiodine in milk, but their breast-feeding infants should still receive potassium iodide (15). Potential potassium iodide side effects include rashes, allergic reactions and gastrointestinal symptoms, and patients with underlying thyroid disease can develop iodine-induced thyroid dysfunction (5). Because the protective effect of potassium iodide lasts for only 24 h, patients with continued exposure through ingestion or inhalation should continue to receive daily doses until the significant exposure has ceased. Physicians should avoid repeat potassium iodide dosing in infants to reduce the risk of hypothyroidism during the critical stage of brain development. Likewise, physicians should avoid repeat dosing in pregnant and lactating women if possible. If repeat dosing is necessary, the

Table 4.6 FDA recommendations for potassium iodide administration

Threshold thyroid radioactive exposures and recommended doses of KI for different risk groups				
	Predicted thyroid exposure (cGy)	KI dose (mg)	No. of 130 mg tablets	No. of 65 mg tablets
Adults over 40 years	≥500			
Adults over 18 through 40 years	≥10	130	1	2
Pregnant or lactating women	≥5			
Adoles over 12 through 18 years ^a	≥5	65	1/2	1
Children over 3 through 12 years ^a	≥5			
Over 1 month through 3 years	≥5	32	1/4	1/2
Birth through 1 month	≥5	16	1/8	1/4

From United States Food and Drug Administration, Center for Drug Evaluation and Research. Guidance: Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies, <http://www.fda.gov/cder/guidance/4825fnl.pdf>.

^aAdolescents approaching adult size (≥ 70 kg) should receive the full adult dose (130 mg)

neonate will require T4 and TSH monitoring with administration of thyroid hormone if hypothyroidism develops (15).

The FDA has approved the oral administration of Prussian Blue (ferric hexacyanoferrate) to treat internal contamination with cesium and thallium (16). Prussian Blue works by increasing fecal excretion of these elements. Patients require treatment only if the exposure dose of ¹³⁷Cs exceeds the annual limit (200 uCi from inhalation or 100 uCi from ingestion) (5). Clinicians should consult with a health physicist to determine whether exposure has exceeded the annual limit. Treatment for exposures between one and ten times the annual limit is controversial. However, exposures exceeding ten times the limit usually indicate the need for treatment. Once treatment has reduced the level of internal contamination below the annual limit, Prussian Blue treatment can stop. However, the clinician can use his or her discretion to discontinue treatment if residual levels remain above the annual limit after prolonged treatment (5).

The FDA recommends 3 g Prussian Blue three times daily for adolescents and adults and 1 g three times daily for children aged 2–12 years for a minimum of 30 days. Clinicians can adjust the dosage and length of treatment based on the level of internal contamination. The chief Prussian Blue side effect is constipation, and clinicians should use Prussian Blue carefully for patients with impaired gastrointestinal motility (5).

Patients suffering from internal contamination with the transuranic elements (plutonium, americium and curium) should receive treatment with the chelating agents, Ca-DTPA and Zn-DTPA. These agents react with the transuranic elements to form complexes amenable to urinary excretion. For adults, the FDA recommends a 1 g loading dose of Ca-DTPA administered intravenously as soon as feasible after exposure. Children younger than 12 years of age should receive 14 mg kg⁻¹ Ca-DTPA intravenously. Because Ca-DTPA is teratogenic, pregnant women should receive Zn-DTPA instead if it is available. Maintenance treatment is 1 g Zn-DTPA

for adults or 14 mg kg^{-1} Zn-DTPA for children given intravenously once per day for days, months or years, depending on the level of internal contamination. Administration of Ca-DTPA by nebulizer is also effective. Clinicians caring for patients receiving chelation treatment should monitor serum levels of trace minerals, such as zinc, magnesium and manganese, throughout the course of therapy (5).

Radiation Injury: Treatment

Following initial triage, stabilization, external decontamination, dose assessment and internal decontamination, clinicians should categorize patients into appropriate treatment groups based on general treatment guidelines (2). These guidelines should complement but not replace clinical judgment. Patients with low ($<1 \text{ Gy}$) exposure doses do not require treatment for ARS. Those with very high ($>10 \text{ Gy}$) doses require only supportive and comfort care because of the grave prognosis (2). Table 4.7 summarizes the recommended guidelines for patient categorization. Because the hematopoietic syndrome is responsible for most of the mortality below 10 Gy of exposure, treatment for radiation injury is directly chiefly at the hematopoietic syndrome. Treatment of the hematopoietic syndrome includes cytokine (colony-stimulating factors) therapy, transfusion and stem-cell transplantation. Short-term treatment with cytokines may be appropriate for relatively low exposure doses ($\leq 3 \text{ Gy}$). Patients with higher exposure levels, for example, above 7 Gy , or those with concomitant traumatic injuries or burns, may require prolonged treatment with cytokines, blood component transfusions and stem cell transplantation (SCT) (5). In addition, patients with the hematopoietic syndrome may need antibiotics for prophylaxis or treatment of infections.

Treatment of the Hematopoietic Syndrome

Cytokine Therapy

Cytokine therapy works by enhancing the survival, amplification and differentiation of granulocyte progenitor cells. Currently, three recombinant cytokines, sargramostim (granulocyte macrophage colony stimulating factor), filgrastim (granulocyte colony stimulating factor) and pegfilgrastim (pegylated filgrastim) are licensed for treating chemotherapy-induced neutropenia (2,5). Although the FDA has not approved any of these agents for managing radiation-induced aplasia, the Radiation Studies Branch at the CDC has recently developed an investigational new drug protocol for their use in patients exposed to high doses of ionizing radiation (5).

Evidence for the effectiveness of these agents comes from their use in cancer patients, human radiation accident victims, and animal studies. Filgrastim and sargramostim have hastened neutrophil recovery 3–6 days in patients following

Table 4.7 Guidelines for treatment of radiologic victims^a

Variable	Proposed radiation dose range for treatment with cytokines	Proposed radiation dose range for treatment with antibiotics ^b	Proposed radiation dose range for referral for SCT consideration
	←————— Gy —————→		
Small-volume scenario (≤100 casualties)			
Healthy person, no other injuries	3–10 ^c	2–10 ^d	7–10 for allogeneic SCT; 4–10. If previous autograft stored or syngeneic donor available
Multiple injuries or burns	2–6 ^c	2–6 ^d	NA
Mass casualty scenario (>100 casualties)			
Healthy person, no other injuries	3–7 ^c	2–7 ^d	7–10 for allogeneic SCT; 4–10 if previous autograft stored or syngeneic donor available
Multiple injuries or burns	2–6 ^c	2–6 ^{d,e}	NA

Source: Waselenko JK, et al. (2), Reprinted by permission of the American College of Physicians

^aConsensus guidance for treatment is based on threshold whole-body or significant partial-body exposure does. Events due to a detonation of a RDD resulting in ≤100 casualties and those due to detonation of an improvised nuclear device resulting in >100 casualties have been considered. These guidelines are intended to supplement (and not substitute for) clinical findings based on examination of the patient. NA = not applicable; SCT = stem-cell transplantation

^bProphylactic antibiotics include a fluoroquinolone, acyclovir (if patient is seropositive for herpes simplex virus or has a medical history of this virus), and fluconazole when absolute neutrophil count is $<0.500 \times 10^9$ cells L⁻¹

^cConsider initiating therapy at lower exposure dose in nonadolescent children and elderly persons. Initiate treatment with granulocyte colony-stimulating factor or granulocyte-macrophage colony-stimulating factor in victims who develop an absolute neutrophil count $<0.500 \times 10^9$ cells L⁻¹ and are not already receiving colony stimulating factor

^dAbsolute neutrophil count $<0.500 \times 10^9$ cells L⁻¹. Antibiotic therapy should be continued until neutrophil recovery has occurred. Follow Infectious Diseases Society of America guidelines (17) for febrile neutropenia if fever develops while the patient is taking prophylactic medication

^eIf resources are available

myelotoxic therapies, including bone marrow and SCT. Neutrophil recovery time was similar whether patients received early or delayed filgrastim therapy after transplantation (5). In the Radiation Emergency Assistance Center Center/Training Site (REACT/TS) registry of radiation accident victims (<http://www.orau.gov/reacts/registry.htm>), patients receiving filgrastim and sargramostim have had faster neutrophil recovery following radiation accidents. However, there was variation in the administration of these agents, making it difficult to draw conclusions about the clinical effectiveness of these agents following radiation exposure. For example,

many of the patients in the registry received both agents, patients received therapy at various intervals after exposure, and some patients received interleukin-3 (2,5). In contrast to the human studies, several studies involving rhesus macaques have demonstrated a shortening of the period of severe neutropenia following administration of colony stimulating factors within 1–2 days post-60-Cobalt irradiation (5).

Table 4.8 contains the Strategic National Stockpile Radiation Working Group recommendations for cytokine treatment following exposure to ionizing radiation (2). Once biodosimetry reveals that a patient has suffered from whole-body or significant partial-body exposure greater than 3Gy (>2Gy for patients with multiple injuries or burns), or if clinical signs and symptoms reveal a level three or four degree of hematotoxicity (see Table 4.9), clinicians should immediately begin cytokine therapy. Later, the clinician can adjust cytokine dosage based on other information, such as chromosome dicentrics. Although lab studies may reveal an

Table 4.8 Recommended doses of cytokines

Cytokine	Adults	Children	Pregnant women ^a	Precautions
G-CSF or filgrastim	Subcutaneous administration of 5 µg kg ⁻¹ of body weight per day, continued until ANC >1.0 × 10 ⁹ cells L ⁻¹	Subcutaneous administration of 5 µg kg ⁻¹ per day, continued until ANC >1.0 × 10 ⁹ cells L ⁻¹	Class C (same as adults)	Sickle-cell hemoglobinopathies, significant coronary artery disease, ARDS; consider discontinuation if pulmonary infiltrates develop at neutrophil recovery
Pegylated G-CSF or pegfilgrastim	One subcutaneous dose, 6 mg	For adolescents >45 kg: one subcutaneous dose, 6 mg	Class C (same as adults)	Sickle-cell hemoglobinopathies, significant coronary artery disease, ARDS
GM-CSF or sargramostim	Subcutaneous administration of 250 µg m ⁻² per day, continued until ANC >1.0 × 10 ⁹ cells L ⁻¹	Subcutaneous administration of 250 µg m ⁻² per day, continued until ANC >1.0 × 10 ⁹ cells L ⁻¹	Class C (same as adults)	Sickle-cell hemoglobinopathies, significant coronary artery disease, ARDS; consider discontinuation if pulmonary infiltrates develop at neutrophil recovery

Source: Waselenko et al. (2), Reprinted by permission of The American College of Physicians. ANC absolute neutrophil count, ARDS acute respiratory distress syndrome, G-CSF granulocyte colony-stimulating factor, GM-CSF granulocyte-inacrophage colony-stimulating factor

^aExperts in biodosimetry must be consulted. Any pregnant patient with exposure to radiation should be evaluated by a health physicist and maternal-fetal specialist for an assessment of risk to the fetus. Class C refers to US Food and Drug Administration Pregnancy Category C, which indicates that studies have shown animal, teratogenic, or embryocidal effects, but there are no adequate controlled studies in women; or no studies are available in animals or pregnant women

Table 4.9 Levels of hematopoietic toxicity^a

Symptom or sign	Degree 1	Degree 2	Degree 3	Degree 4
Lymphocyte changes ^b	$\geq 1.5 \times 10^9$ cells L^{-1}	$1-1.5 \times 10^9$ cells L^{-1}	$0.5-1 \times 10^9$ cells L^{-1}	$<0.5 \times 10^9$ cells L^{-1}
Granulocyte changes ^c	$\geq 2 \times 10^9$ cells L^{-1}	$1-2 \times 10^9$ cells L^{-1}	$0.5-1 \times 10^9$ cells L^{-1}	$<0.5 \times 10^9$ cells L^{-1}
Thrombocyte changes ^d	$\geq 100 \times 10^9$ cells L^{-1}	$50-100 \times 10^9$ cells L^{-1}	$20-50 \times 10^9$ cells L^{-1}	$<20 \times 10^9$ cells L^{-1}
Blood loss	Petechiae, easy bruising, normal hemoglobin level	Mild blood loss with $<10\%$ decrease in hemoglobin level	Gross blood loss with $10-20\%$ decrease in hemoglobin level	Spontaneous bleeding or blood loss with $>20\%$ decrease in hemoglobin level

Source: Waselenko et al. (2), by permission of the American College of Physicians.

^aModified from Dainiak N (24)

^bReference value, $1.4-3.5 \times 10^9$ cells L^{-1}

^cReference value, $4-9 \times 10^9$ cells L^{-1}

^dReference value, $1.40-400 \times 10^9$ cells L^{-1}

initial granulocytosis followed by neutropenia, the patient should receive cytokine therapy continuously. Once the absolute neutrophil count rebounds from its nadir and reaches 1.0×10^9 cells L^{-1} , it is appropriate to discontinue cytokine treatment. However, monitoring should continue, and clinicians should resume cytokine treatment if the neutrophil count declines significantly ($< 0.5 \times 10^9$ cells L^{-1}) after discontinuation of initial cytokine treatment.

Children younger than 12, adults over 60 and patients of any age with multiple injuries or burns are generally more susceptible to radiation injury. Therefore, these patients should receive cytokine therapy at lower levels (>2 Gy) of whole or partial-body exposure. Patients with exposures above 6–7 Gy involved in an accident with over 100 casualties will generally have a poor prognosis for survival. In such events involving mass casualties, given the level of resources available, it may make sense to withhold cytokine treatment from these patients, especially if they also suffer from significant traumatic injuries or burns. Given that cytokines are expensive and critical resources requiring administration for long periods, physicians may have to make difficult triage decisions regarding their use. For example, it may be prudent to give cytokine treatment preferably to patients without additional injuries because of their greater chance for survival, such as adults under 60 with 3–7 Gy exposures and children and adults ≥ 60 with 2–7 Gy exposures. Cytokine doses are equivalent to those given to patients with chemotherapy related neutropenia (2).

In addition to cytokines, patients with anemia may benefit from receiving epoetin and darbepoetin, even though studies have not established their effectiveness following radiation accidents (2). The response to these agents takes up to 3–6 weeks, and patients may require supplementation with iron (2).

Transfusion

Patients with severe bone marrow dysfunction will require cellular component transfusions, such as packed red blood cells and platelets. Hospitals and health care providers caring for victims of radiological events will have time to mobilize potential blood donors, because bone marrow suppression generally occurs 2–4 weeks following exposure. Of course, trauma patients may require immediate transfusion due to blood loss. Because bone marrow suppression is associated with immunosuppression, the cellular components must undergo leukoreduction and irradiation (25 Gy) to prevent transfusion-associated graft-versus-host disease in the recipients. Clinicians caring for transfused patients may have trouble differentiating graft-versus-host complications from direct radiation-induced organ damage. Symptoms of both may include fever, pancytopenia, rashes, desquamation, diarrhea, and liver function abnormalities. In addition to preventing graft-versus-host disease, leukoreduction of the cell components before transfusion reduces the frequency of febrile nonhemolytic reactions, reduces the immunosuppressive effects of the transfusion and provides protection against platelet alloimmunization and cytomegalovirus infections (2).

Stem Cell Transplantation

Most of the data related to the effectiveness of SCT are from its use in patients with hematological malignant conditions. For these conditions, matched related and unrelated allogeneic SCT have been life saving and potentially curative (2). Experience is limited and less positive for SCT in treating patients with radiation-induced bone marrow aplasia following radiation accidents. Although radiation accident victims have experienced transient engraftment, their outcomes have been dismal secondary to associated burns, trauma and radiation damage to other organs. A review of 29 cases involving SCT treatment of radiation accident victims revealed that all patients with burns died and only three of the 29 victims survived beyond 1 year. The review did not indicate whether the SCT affected survival (2). SCT of two patients following a 1999 radiation accident in Japan had similar results, with both patients experiencing donor-cell engraftment before going on to die of radiation-induced organ damage or infection (2).

Given our experience with SCT following radiation exposure, clinicians should consider SCT following exposures of 7–10 Gy in patients without accompanying burns or other major organ toxicity and if a suitable donor is available (see Table 4.7). Patients demonstrating residual hematopoiesis (granulocyte counts above 0.50×10^9 cells L^{-1} and platelet counts exceeding 100×10^9 cells L^{-1} 6 days after exposure) may not be candidates for SCT. Nevertheless, clinicians should consider stem cell infusions for patients with exposures above 4 Gy when (rarely) a syngeneic donor or previously harvested autologous bone marrow is available (2).

Infection treatment and prophylaxis: Victims of radiological attacks are at risk for infection due to disruption of the skin or mucosal barriers and due immune suppression from a reduction in lymphohematopoietic cells (2). Studies in irradiated dogs have revealed a reduction in mortality following antibiotic administration. During the neutropenic phase, control of infections is especially important. Patients who are not neutropenic should receive antibiotics directed at specific foci of infection caused by the most likely pathogens. On the other hand, neutropenic patients may benefit from prophylaxis with fluoroquinolones. Patients with severe neutropenia (absolute neutrophil count $<0.500 \times 10^9$ cells L^{-1}) should receive prophylaxis with broad-spectrum antibiotics while the neutropenia lasts. Prophylaxis may include (2):

- A fluoroquinolone with streptococcal coverage or a fluoroquinolone without streptococcal coverage plus penicillin (or a penicillin congener)
- An antiviral agent (acyclovir or one of its congeners)
- An antifungal agent (such as fluconazole)

In murine studies, quinolones have been effective in controlling endogenous gram-negative systemic infections following radiation. Quinolones are also effective in preventing endogenous Klebsiella and Pseudomonas infections. In addition, penicillin supplementation has prevented treatment failures in cancer patients with treatment-induced neutropenia (2).

Patients should receive antibiotics until the neutrophil count improves ($>0.500 \times 10^9$ cells L^{-1}) or until they develop neutropenic fever or some other indication that the antibiotics are not effective. Patients developing specific focal infections while neutropenic should receive antibiotics directed at the cause of the infection. Clinicians should withdraw quinolone treatment for patients developing a fever while receiving the fluoroquinolone and should instead treat for a gram-negative infection such as Pseudomonas aeruginosa, which can be rapidly fatal in a neutropenic patient (2). If available, primary care physicians may want to consult with an infectious disease specialist familiar with the recommendations of the Infectious Diseases Society of America. Because animal studies have revealed that altering the anaerobic gut flora may worsen outcomes, patients should not receive gut prophylaxis unless they have a clinical indication, such as an abdominal wound or *Clostridium difficile* enterocolitis (2).

Immunosuppressed radiation victims with positive serology for herpes simplex viruses are at risk for reactivation of HSV infection, with resulting clinical picture that mimics radiation stomatitis. These patients should receive prophylaxis with acyclovir or one of its congeners. If serology results are not available, patients with a history of oral or genital herpes infection should receive acyclovir prophylaxis. Patients who develop severe mucositis require assessment for HSV reactivation (2).

Studies in patients undergoing allogeneic bone marrow transplantation have revealed that oral fluconazole, 400 mg d^{-1} , is effective in reducing the severity of invasive fungal infections and subsequent mortality. The evidence of fluconazole effectiveness is less clear in patients with bone marrow suppression secondary to chemotherapy.

Immunosuppressed radiation victims may also be at risk for reactivation of cytomegalovirus (CMV) and *Pneumocystis carinii* pneumonia. In a limited casualty situation, if resources are available, clinicians should obtain CMV serology. In addition, patients should have a sensitive assay (antigen assessment or polymerase chain reaction test) every 2 weeks for 30 days postexposure, while those with documented previous CMV exposure should have the assay repeated until 100 days postexposure (2). Patients developing lymphopenia should have a CD4 cell count considered at 30 days postexposure. Those with a CD4 count below 0.2000×10^9 cells L^{-1} are at risk for *Pneumocystis carinii* pneumonia. Physicians should withhold trimethoprim-sulfa prophylaxis until the leukocyte count is above 3.0×10^9 cells L^{-1} or until the absolute neutrophil count is above 1.5×10^9 cells L^{-1} . Atovaquone, dapsone and aerosolized pentamidine are alternative prophylactic agents. Patients should continue prophylactic treatment until the CD4 count reaches or exceeds 0.2000×10^9 cells L^{-1} , which may occur over several months (2).

Supportive and Comfort Care

Supportive and comfort care include administration of antiemetic agents, anti-diarrheal agents, fluids, electrolytes, analgesia and topical burn creams. Radiation victims developing multiorgan failure within hours of exposure should receive only expectant care (treatment for comfort with psychosocial support) because they were undoubtedly received an exposure greater than 10 Gy and their prognosis is grave.

On the other hand, patients developing multiorgan failure several days to weeks after exposure should receive routine critical care because they have likely received a moderate exposure and have a reasonable chance of survival. Significant burns, hypovolemia and hypotension require early resuscitation with fluids. Additional critical care may include endotracheal intubation, anticonvulsant agents, anxiolytic agents and sedatives as necessary (2).

Radiation victims should not receive prophylaxis for nausea and vomiting for a couple of reasons. First, the time from exposure to onset of these symptoms is a useful component of exposure assessment. Secondly, the short onset time for clinically significant exposures makes prophylaxis for vomiting impractical. At low exposure doses, the duration of vomiting varies from about 48 to 72 h, making prolonged antiemetic therapy unnecessary. Prophylaxis for gastrointestinal ulceration is an additional component of supportive care. Physicians should avoid instrumentation of the gastrointestinal tract, since the mucosa is friable and likely to slough and bleed following instrumentation.

Radiation victims exposed to doses greater than 10–12 Gy have virtually no chance for survival, and are therefore not candidates for definitive care. These patients should receive comfort measures rather than aggressive definitive treatment. Comfort measures should include analgesia, antiemetic agents and anti-diarrheal agents. In addition, these patients, their families and their friends would benefit from psychological support and spiritual care.

References

1. Leikin, JB, McFee, RB, Walter, FG, Edsall, K. A Primer for Nuclear Terrorism. *Disease-a-Month*, 49(8):485–516, 2003
2. Waselenko, JK, MacVittie, TJ, Blakely, WF, et al. Medical Management of the ARS: Recommendations of the Strategic National Stockpile Radiation Working Group. *Annals of Internal Medicine*, 140(12):1037–1051, 2004
3. Federation of American Scientists. Special Weapons Primer. Weapons of Mass Destruction. <http://www.fas.org/nuke/intro/nuke/intro.htm>, last accessed 9–04–05
4. Hogan, DE, Kellison, T. Nuclear Terrorism. *The American Journal of the Medical Sciences*, 323(6):341–349, 2002
5. Koenig, KL, Goans, RE, Hatchett, RJ, et al. Medical Treatment of Radiological Casualties: Current Concepts. *Annals of Emergency Medicine*, 45(6):643–652, 2005
6. Ring, JP. Radiation Risks and Dirty Bombs. *Health Physics* 86(2 Suppl.):S42–S47, 2004
7. Military Medical Operations Armed Forces Radiobiology Research Institute. Medical Management of Radiological Casualties Handbook. Second Edition. Bethesda, Maryland 20889–5603 <http://www.afri.usuhs.mil> April 2003
8. Centers for Disease Control and Prevention. ARS: A Fact Sheet for Physicians, <http://www.bt.cdc.gov/radiation/pdf/arsphysicianfactsheet.pdf>, last accessed 9–11–05
9. Oak Ridge Associated Universities, Oak Ridge Institute for Science and Education. Guidance for Radiation Accident Management, Managing Radiation Emergencies, Guidance for Hospital Medical Management. Radiation Emergency Assistance Center/Training Site (REAC/TS), <http://www.ornl.gov/reacts>, last accessed 1–01–06
10. Walker, RI, Cerveney, RJ (Eds.). *Textbook of Military Medicine Medical Consequences of Nuclear Warfare*. Falls Church, VA: Office of the Surgeon General, 1989. Available at <http://www.afri.usuhs.mil>
11. Goans, RE, Holloway, EC, Berger, ME, Ricks, RCF. Early Dose Assessment in Criticality Accidents. *Health Physics*, 81(4):446–449, 2001
12. Military Medical Operations Armed Forces Radiobiology Research Institute. Biodosimetry Assessment Tool (BAT) Software Application. <http://www.afri.usuhs.mil/www/outreach/biodostools.htm#BATregister>, last accessed 12/31/05
13. Centers for Disease Control and Prevention. Prenatal Radiation Exposure: A Fact Sheet for Physicians, March 23, 2005. <http://www.bt.cdc.gov/radiation/pdf/prenatalphysician.pdf>, last accessed 1–29–06
14. National Council on Radiation Protection and Measurements. NCRP Report No. 128: Radionuclide Exposure of the Embryo/Fetus. Bethesda, Maryland: NCRP, 1998, <http://www.ncrponline.org/ncrprpts.html> (last accessed 1–29–06)
15. United States Food and Drug Administration, Center for Drug Evaluation and Research. Guidance: Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies, <http://www.fda.gov/cder/guidance/4825f1.pdf>, last accessed 1–01–06
16. United States Food and Drug Administration, Center for Drug Evaluation and Research. Guidance for Industry on Prussian Blue for Treatment of Internal Contamination with Thallium or Radioactive Cesium, Availability. *Federal Register/Vol. 68, No. 23/Tuesday, February 4, 2003/Notices*, <http://www.fda.gov/OHRMS/DOCKETS/98fr/03-2597.pdf>, last accessed 1–01–06
17. Hughes, WT, Armstrong, DN, Bodey, GP, et al. Guidelines for the use of Antimicrobial Agents in Neutropenic patients with Cancer. *Clinical Infectious Diseases*, 34:730–751, 2002.