Mass exposure to radiologic substances presents a unique challenge to the entire response effort, which includes health care professionals, law enforcement personnel, and other first responders. Recognition of signs and symptoms of exposure, and focus on removal and decontamination are priorities of management. Radiation injuries require specialized equipment and access to experts. Patients can have complex patterns of injury, ranging from trauma and the immediate results of an explosion or exposure, to progressive damage associated with radiation sickness. Both conventional injury and radiation illness may require critical care management. Remembering the essentials of first response, that is, treat the patient, not the poison, by addressing the ABCs of airway, breathing, and circulation, is critical to appropriate treatment of radiation exposure. Understanding the basic science of radiologic agents will aid the provider in managing affected patients and preventing further casualties.
Preparedness efforts in terms of weapons of mass destruction and methods of terrorizing a population have clearly emphasized biologic agents and chemical threats. Medical training concerning radiation poisoning remains underemphasized, despite the potential risk radiation terrorism poses in that radiation sources are ubiquitous and are available from medical, industrial, and military sources (Table 1). Such widespread proliferation of nuclear materials increases the probability that some form of radiation will be used as a weapon. The potential for a radiation event can result from terrorism, as in the Chechen threat to use a radiation dispersal device (RDD) containing cesium 137 in Moscow, or from the mishandled disposal of a medical radiotherapy device in Brazil, which was responsible for the worst radiation accident in the western hemisphere. Chernobyl and scattered other high profile events, although relatively rare, demonstrate that, when they do occur, the potential for multiple casualties and long-term illness is great. An RDD is any device that causes purposeful dissemination of radioactive material across an area, without nuclear detonation (Table 2). Such devices can be produced by blowing up a radioactive source with conventional explosives. An RDD causes conventional blast-related casualties contaminated with radionuclides. An alternative, a simple dispersal device (SDD), is a source of radioactive material that does not rely on an explosion to cause harm, but on the normal radioactivity of the source material. In this era of terrorism, clinicians may be the first to identify sentinel cases, and thus must think in terms of complex presentations from multiple and simultaneous injury sources, and communicate suspicions, concerns, and observations to appropriate members of response teams. Although most major metropolitan areas have designated nuclear response hospitals, a RDD may be used closer to a community hospital than a tertiary care facility. Medical management of patients with suspected exposure, no exposure but significant psychological trauma, or a major medical emergency, and possibly posing the threat of contamination, will depend on advanced training, appropriate equipment, and trained personnel. Our concerns as health care professionals cannot be limited to Cold War terms of nuclear holocaust, but must include preparedness against “dirty bombs,” such as RDD, as well as increased knowledge of management of industrial incidents.

**Nuclear Casualties**

Management of patients exposed to or contaminated by radioactive material is directed toward rapid recognition, prevention of secondary
contamination, patient decontamination, and appropriate intervention, referral, and follow-up. 7-9

In radiation exposure, the radiation source is less important than the dose produced. If the dose produced is high enough, regardless of the source, biologic damage will result. The bad news about radiation is that our senses cannot detect radiation. We cannot see, smell, hear, taste, or feel radiation. Before early symptoms of radiation sickness develop, and in the absence of explosion-related disease, a lethal dose of radiation can be delivered without our immediately realizing it.9

Managing a radiation victim is guided in part by whether the patient was contaminated or irradiated. A contaminated patient has radioactive material on the body or clothes, and thus poses the risk for spread of the contaminant to others and the environment. An irradiated patient poses no threat to health care providers, and treatment can be provided without use of special protective gear.

There are four methods of radiation exposure:

1. **Irradiation.** Irradiation is radiation exposure without contamination. There is no need to delay treatment; no decontamination is necessary.

2. **External contamination.** Radionuclides are present on external body surfaces and may be transferred. Precautions must be taken to avert contamination of health care workers and facilities.

3. **Internal contamination.** Radionuclides can be deposited internally by inhalation, ingestion, injection, or wounds. These particles can then become incorporated in the body.

4. **Combined injury.** RDD or nuclear explosion can result in blast or mechanical injury, burns, and radiation injury. Treatment of life-threatening non-radiation-related injuries should not be delayed in favor of treatment of radiation-related illness.

It is important to mention, although beyond the scope of this article, that the psychological effects of any radiation event include profound acute?

**TABLE 1. Classification of radiologic nuclear terrorism**

<table>
<thead>
<tr>
<th>Name</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple radiologic device</td>
<td>Placing high gamma source (Ir, Cs, Co) in busy public place</td>
</tr>
<tr>
<td>Radiologic dispersal device</td>
<td>Spreading radioactive material with conventional explosion</td>
</tr>
<tr>
<td>(&quot;dirty bomb&quot;)</td>
<td></td>
</tr>
<tr>
<td>Nuclear reactor sabotage</td>
<td>Disabling nuclear reactor cooling system</td>
</tr>
<tr>
<td>Improvised nuclear device</td>
<td>Detonating homemade nuclear device in a city</td>
</tr>
<tr>
<td>Nuclear weapon</td>
<td>Detonating 1 kiloton, suitcase-sized nuclear weapon pirated from one of the nuclear powers of the world</td>
</tr>
</tbody>
</table>

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and chronic stress disorders, possible somatization responses, and large numbers of walking, worried well patients.\textsuperscript{10}

**Nuclear Radiation**

**Ionizing Radiation**

Ionizing radiation consists of electromagnetic energy or energetic particles emitted from a source. Ionizing radiation can strip electrons from atoms to cause chemical change, resulting in biologic damage. Ionizing radiation can occur naturally, or be generated or produced from radioactive atoms.

The basic building block of all matter is the atom, which consists of a central nucleus surrounded by defined shells of electrons orbiting around it.

The main part of the atom of concern is the nucleus. The nucleus has two basic building blocks, the neutron and the proton. The neutron, as its name implies, is neutral; the proton is positively charged. Positively charged particles tend to repel each other; therefore, to hold this nucleus together requires a special nuclear glue, which has mass, or “binding energy.” This binding energy has three important characteristics: it is strong, acts over a short range, and is independent of charge. Each element is defined by the number of protons in its nucleus, or atomic number.

For a stable element the ratio of protons to neutrons is 1:1.2. In a radioactive nucleus this ratio is in imbalance, usually with an excess of neutrons.

The unstable nucleus can become stable by altering its components. A neutron can change into a proton with emission of a negative electron, or beta particle.

\[
\text{Neutron} + \text{Proton} + -\text{ve Electron}
\]

A proton can change into a neutron with emission of a positive electron, or positron. Note that a positron cannot survive on its own, and is annihilated. When a positron meets a negative electron, both particles are

<table>
<thead>
<tr>
<th>Source</th>
<th>Major Radionuclides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical diagnostic and therapeutic facilities</td>
<td>Carbon 14 X</td>
</tr>
<tr>
<td>Research laboratories</td>
<td>X X X</td>
</tr>
<tr>
<td>Industrial imaging and sterilizing facilities</td>
<td>X X</td>
</tr>
</tbody>
</table>

TABLE 2. Simple radiologic device and “dirty bomb” sources

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DM, August 2003
changed into energy, producing two gamma photons of 0.5 MeV (mega electron volt).

Proton = Neutron + +ve Electron

Thus the unstable nucleus can interchange its component parts to reaching a proton-neutron ratio of 1:1.2. Note that if the proton number changes, a completely different element is formed.

Is the new nucleus that is formed, with the correct proton-neutron ratio, stable? No. Why? To answer this question one must consider the nuclear glue (binding energy). As a result of particles having been ejected from the nucleus there is an excess of nuclear glue, which has mass. This excess mass is changed into electromagnetic energy with very short wavelength, and this is where gamma irradiation is derived. Thus the nucleus finally becomes stable.

Unstable heavy elements have the capability to eject larger particles consisting of two protons and two neutrons, or alpha particles (Table 3).

Types of radiation that are of concern are alpha particles, beta particles, neutrons, gamma rays, and x-rays.

**Alpha particles.** Alpha particles consist of two protons and two neutrons. With two protons, which are positively charged, they are very reactive. Alpha particles are capable of traveling 2 to 3 cm in air, but only microns into tissue. They can be stopped completely by a piece of paper, and therefore are stopped by clothing. An alpha particle that lands on the skin is not a problem, because the outer layers of skin are dead and are several microns thick. The alpha particle generally will not penetrate through the dead layers of skin to the live layers and cause damage. Therefore alpha particles are not an external hazard. In contrast, if an alpha particle enters the body via ingestion, inhalation, or a wound, it is adjacent to live tissue and can cause serious damage to the immediate tissue a few microns deep. Therefore alpha particles are an internal hazard.
**Beta particles.** Beta particles are high-energy electrons emitted from a nucleus. They can travel about a meter through air and millimeters into skin. Beta particles have a spectrum of energy, depending on the radioactive isotope concerned. This energy are measured in mega electron volts. The higher the electron volts the deeper the penetration; for example, beta particles with 0.1 MeV energy will penetrate 0.15 cm into tissue, and beta particles with 5 MeV energy will penetrate 5 cm into tissue. Beta particles allowed to remain on the skin for long periods can cause severe burns to the skin and also to the anterior compartment of the eye. Beta particles are also a hazard if they are internally deposited in the body.

**Neutrons.** As the name implies, neutrons are neutral. They are very penetrating, and cause damage via two main pathways: collision, imparting energy to other particles (“billiard ball” effect), and neutron capture. Certain elements have the affinity to capture neutrons. One element of concern is sodium. When the body is exposed to a flux of neutrons, body sodium 23 has the affinity to capture a neutron and become sodium 24, which is radioactive. This is one of the ways by which a person becomes radioactive.

**Gamma rays.** Gamma rays are very high-energy rays with short wavelength that are very penetrating. They can travel many meters in air and many centimeters into tissue. Clothing is not protective against gamma rays, but will prevent contamination of skin from gamma-emitting radioactive isotopes.

**X-rays.** X-rays are similar to gamma rays, but with a longer wavelength. X-rays are produced as the result of high-energy electrons passing a positive nucleus; the electron slows, giving off x-rays. This is called braking radiation, or bremsstrahlung. X-rays, like gamma rays, are very penetrating. Generally they are an external hazard, because they are produced by a generating machine.

It should be noted that, in addition to type, source, and threat of radioactivity, some elements may pose an additional toxic threat, depending on their state of matter, external temperature, and circumstances of
exposure, from corrosion or explosion. Cesium, for example, is an alkali metal, and can explode if exposed to water. Cesium hydroxide is a strong base and attacks glass. It is the most electropositive and alkaline element, and one of the few metals that is liquid at or about room temperature. Cesium reacts with ice at temperatures above $-116^\circ$C. Therefore the response team should attempt to identify the radionuclide source, the element or chemical involved, and associated critical information such as flash point, type of radiation emission (beta, gamma, alpha), and other characteristics that may pose a risk to patient and health care worker. Cesium is found in nature as a single stable isotope, cesium 133. However there are 30 other radioactive isotopes of cesium, from $^{114}$Cs to $^{145}$Cs, with half-life ranging from 0.57 seconds ($^{114}$Cs) to $3 \times 10^6$ years ($^{135}$Cs). $^{137}$Cs is commonly used in medical and industrial applications, has a relatively long half-life, and thus could be used with tetrynitroblue tetrazolium or other explosive chemicals to create a “dirty” RDD device, or left unshielded as an SDD. $^{137}$Cs emits both gamma and beta radiation. It is completely absorbed by the lungs and gastrointestinal (GI) tract, and is internalized via wounds. $^{137}$Cs is soluble in most forms, and is metabolically handled like a potassium analog, with urinary excretion. Death has occurred from cesium-related acute radiation syndrome (ARS).

Therefore, in this era of terrorism, explosives not only create blast and thermal damage, they now can be mixed with toxic chemicals or radionuclides. The clinician must be aware of the spectrum of risk that these chemicals and events can present, and the requisite assets necessary to manage such exigencies. Although the ensuing radiation risk could be minimal, the terrorism value of spreading even a low-yield, low-threat source of radiation would be effective in terms of public concern and possible panic.

Radiation hazard is related to the strength of the source (radioactivity) and the total radioactive energy absorbed per unit volume of tissue (dose). Activity is the number of radioactive disintegrations per second, given as curies (Ci) or becquerels (Bq) ($1$ Ci = $3.7 \times 10^{10}$ Bq). Biologic injury from a given type of ionizing radiation depends on the amount of radioactive energy deposited in a physiologically critical volume of tissue. This is quantified by units of absorbed dose.

**Time.** Exposure and absorption are dose-dependent and time-dependent. Limiting time in a radiation environment limits exposure. Rotating the medical team results in sharing the dose and keeps individual dose to a minimum.

**Distance.** Keeping maximum distance between oneself and the source of radiation will minimize exposure. The concept of inverse square law applies; that is, if the distance between an object and the source of
exposure is doubled, exposure is reduced to one-fourth its original value. Reduction of exposure is exponential.

For example, if a person stands 2 ft from a source and receives a dose of 160 rad, doubling the distance to 4 ft will reduce the dose received to 40 rad, or one fourth. If the distance is doubled again, to 8 ft, the dose received is reduced to 10 rad. Thus, increasing the distance from 2 ft to 8 ft reduces the dose received from 160 rad to 10 rad (Table 4).

**Shielding (Table 5).** A single piece of paper will stop alpha particles completely. Hospital protective clothing completely protects against alpha particles.

Shielding against beta particles requires a light material, such as aluminum or thick plastic. Materials with low atomic number are used to shield against beta particles, to minimize production of bremsstrahlung (x-rays). Hospital protective clothing will only partially protect against beta irradiation.

In general, materials with high hydrogen content and low atomic number are used to shield against fast neutrons such as paraffin, wax, and water and against thermal neutrons, such as boron or cadmium.

Gamma irradiation is electromagnetic radiation, unlike particulate radiation, and cannot be completely stopped, but only attenuated. However, with shielding it is markedly attenuated, and the level of remaining radiation is very low.

Shielding is provided with lead, concrete, or uranium. In an emergency these materials may be difficult to obtain on short notice; therefore setting up of barriers or limiting exposure time may be the best option.

**Quantity.** The concept of quantity is important in an emergency, especially in-hospital. When dealing with several patients who are contaminated, especially their clothing, do not store their discarded clothing in the emergency department. This would result in a radioactive source in the department, thereby increasing radiation exposure of staff. It is important that contaminated clothing be removed from the emergency department to a designated area outside of the hospital.

**Radiation units.** The basic unit for measuring dose is the rad (radiation absorbed dose) (Table 6), defined as deposition of 0.01 J of energy in 1 kg of tissue. To quantify the amount of damage suspected from radiation exposure, rad are converted to rem (roentgen equivalent-man). The rem is adjusted to reflect the type of radiation absorbed and the likely damage produced. For practical purposes, the rem and the rad are considered equivalent.

In general, rem is used in occupational exposure, whereas rad is used in accidental situations, because of the higher dose of exposure anticipated.
International units. Rem and rad are used only in the United States, whereas international units, that is, the gray (Gy) and the sievert (Sv), are used in the rest of the world. All current publications and textbooks on radiation medicine use the new international units. For conversion of units, 100 rad = 1 Gy, and 100 rem = 1 Sv.

Background Radiation
Radioactivity has existed in Earth’s crust for millions of years. We live in a radiation environment, with exposure from Earth crust radiation, cosmic radiation, and manufactured radiation. The highest contribution of manufactured radiation is in hospital radiology and nuclear medicine departments. We are all radioactive; our bodies contain the radioactive isotopes carbon 14 and potassium 40.

Average radiation background, both natural (80%) and manufactured (20%), in the United States is 360 mrem/y.

It is important to realize that background radiation changes from area to area and day to day. Background radiation is much higher in granite mountainous regions than in the flat plains. It is important to know the background radiation level in your area at the time of an incident, because anything above background level is an indication of contamination.

To put radiation dose into perspective, some examples are given in Table 7.

Exposure, Contamination, and Incorporation
A radiation incident, regardless of source or type, can result in three kinds of radiation injury: external radiation, contamination with radioactive material, and incorporation of radioactive material into body tissues (Tables 8, 9). To these can be added trauma. Any combination of these injuries can occur at the same instant.

External Radiation
External radiation occurs when the entire body or part of the body is exposed to penetrating radiation from an external source. The patient may be seriously injured from radiation, but is no danger to medical staff.

<table>
<thead>
<tr>
<th>Distance from source (ft)</th>
<th>Dose (rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>160</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
</tr>
</tbody>
</table>

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type of exposure does not render the patient radioactive, and he or she can be treated accordingly.

To emphasize this concept, it is similar to taking a patient to the radiology department for a chest x-ray examination. During the x-ray study, you do not become radioactive. The same applies to someone who has been exposed to penetrating radiation.

**Contamination**

Contamination can be external or internal. External contamination results from radioactive materials in the form of a solid, liquid, or gas released into the atmosphere and precipitating down on people. Exposed surfaces, namely, hair and the skin of the neck, face, and hands, can become contaminated. Clothing will be contaminated as well, but simply removing the clothes eliminates 90% of the contamination. Internal contamination is achieved by three main routes, that is, inhalation, ingestion, and wounds, resulting in internal radiation of the organs of entry.

**Incorporation**

Incorporation refers to uptake of radioactive materials by organs, tissue, and cells. In general, materials distributed around the body depend on their physical and chemical forms, and solubility. Incorporation cannot occur unless internal contamination has occurred. If the element or elements incorporated are known, a reasonable idea of the target organ will be known. A word of caution is necessary. In an accident setting, the radioactive isotope or isotopes is known, because all radioactive sources are registered. However, in a terrorism setting, initially the radioactive source or sources are not known.

---

**TABLE 5. Radiologic Protection: Shielding**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Mass (amu)</th>
<th>Charge</th>
<th>Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>Particle</td>
<td>4</td>
<td>+2</td>
<td>Air, cm Stratum corneum (dead outer skin layer) only, 20 μm</td>
</tr>
<tr>
<td>Beta</td>
<td>Particle</td>
<td>1:1823</td>
<td>−1 or +1</td>
<td>Air, m Tissue, mm</td>
</tr>
<tr>
<td>Neutron</td>
<td>Particle</td>
<td>1</td>
<td>0</td>
<td>Air, m Body cm</td>
</tr>
<tr>
<td>X-ray</td>
<td>Ray</td>
<td>0</td>
<td>0</td>
<td>Air m Body, through</td>
</tr>
<tr>
<td>Gamma</td>
<td>Ray</td>
<td>0</td>
<td>0</td>
<td>Air 100 m Body, through</td>
</tr>
</tbody>
</table>

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These three types of events can occur individually or in any combination. In addition, there are the complications of trauma and illness.

**Nuclear Terrorism**

Nuclear terrorism is defined as use of radioactive material in various forms to produce maximum disruption, panic, injury, and fear in the general population.

Five groups of terrorist threat can be considered (Table 1):

- Simple radiologic device
The most plausible threat would be an SRD or RDD, because hundreds of thousands of radioactive sources are available in industry and medicine around the world.

Much information can be gained from previous worldwide radiation accidents in preparing and planning for nuclear terrorism.

**Simple radiologic device.** Use of an SRD is the deliberate act of placing a high-energy source or spreading radioactive material in a highly populated area, such as an airport, train station, port, or sports venue, to expose people to various levels of radiation.

In 1987 in Goiania, Brazil, two thieves stole a $^{137}$Cs hospital therapy source in its shielding and sold it for scrap metal. The source consisted of 1375 Ci of $^{137}$Cs. The source was broken up and shared among various individuals. At the time, these persons were not aware they had a radioactive source, and the incident was not detected for 15 days. The medical response and cleanup phase took several months to complete. In this situation there was both exposure and contamination. The overall findings were as follows:

### TABLE 8. Exposure vs contamination

<table>
<thead>
<tr>
<th>Incident</th>
<th>Radiation Location</th>
<th>Source type</th>
<th>Physical state</th>
<th>Patient decontamination necessary</th>
<th>Secondary contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>External</td>
<td>Rays (energy)</td>
<td>None</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>External contamination</td>
<td>External (skin surface)</td>
<td>Particles (matter)</td>
<td>Solid</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Internal contamination</td>
<td>Internal</td>
<td>Particles (matter)</td>
<td>Liquid-Solid-Gas</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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### TABLE 9. Chemical vs radiologic terminology

<table>
<thead>
<tr>
<th>Chemical vs radiologic terminology</th>
<th>Chemical</th>
<th>Radiologic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorption vs Internal contamination</td>
<td>Absorption vs</td>
<td>Internal contamination</td>
</tr>
<tr>
<td>Distribution vs Incorporation</td>
<td>Distribution</td>
<td>Incorporation</td>
</tr>
<tr>
<td>Metabolism (catabolism) vs Elimination</td>
<td>Metabolism</td>
<td>Incorporation</td>
</tr>
<tr>
<td>Elimination vs Decorporation</td>
<td>Elimination</td>
<td>Decorporation</td>
</tr>
</tbody>
</table>

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- Radiologic dispersal device
- Nuclear reactor
- Improvised nuclear device
- Nuclear weapon

The most plausible threat would be an SRD or RDD, because hundreds of thousands of radioactive sources are available in industry and medicine around the world.

Much information can be gained from previous worldwide radiation accidents in preparing and planning for nuclear terrorism.

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112,800 persons were surveyed for contamination
249 persons were contaminated
120 persons were externally contaminated on clothes and shoes
129 persons were both externally and internally contaminated
20 persons required specific hospital treatment
14 persons had subsequent bone marrow depression
8 persons received treatment with granulocyte-macrophage colony-stimulating factor
4 persons died as a result of hemorrhage and infection

Other places around the world in which stolen radioactive sources resulted in serious radiation injuries include Juarez, Mexico in 1983, involving 450 Ci of cobalt 60, and recently in Thailand, again involving $^{60}\text{Co}$.

In the last few years there have been two incidences of stolen sources. Sixteen brachiotherapy sources of $^{137}\text{Cs}$ were stolen from a hospital in North Carolina, and in Florida an industrial radiography source of iridium 192 was stolen. These sources have not been found.

$^{137}\text{Cs}$ is ubiquitous as a medical and industrial radiation source. A common industrial usage is in the construction of highways, in which it is used in devices that measure density of asphalt. During the last 18 months several such devices in the southeast United States have been stolen or are missing; their whereabouts remain unknown. In addition to radiation risk from $^{137}\text{Cs}$, this substance is highly toxic. It is explosive when exposed to air and water, must be stored in special containment, and can cause significant dermal injury on direct contact.

Hospitals, industry, and scientific research facilities, as opposed to military installations, are especially vulnerable to theft of radioactive materials. Industries that use such materials must implement safeguards and surveillance systems to ensure that these radiation sources remain fully accounted for.

**Radiologic dispersal device (Table 2).** In an RDD, explosives are attached to a radioactive isotope and detonated. This can result in large areas of local contamination, as well as contamination of the people in the area and of responding emergency services. It can also lead to death of several persons as a result of the explosion and from significant exposure to radiation of those close to the scene of the incident. In this type of event a nuclear reaction does not occur.

$^{137}\text{Cs}$ has been identified as a potential radiation source for such a “dirty” device. In this era of terrorism, responders must be aware of the secondary risk in responding to an explosion threat. The risk of a potential
secondary device as well as a “dirty” primary device must always be considered.

**Nuclear reactor (Table 10).** In the western world the probability of a terrorist attack on a nuclear reactor is low, but recent events highlight the possibility. The low probability is due to the high security surrounding a nuclear reactor and the safety systems incorporated into it. There is extensive shielding around a reactor; therefore very significant amounts of explosive would be required to breach the reactor core.

Terrorist events could include use of very large amounts of explosives, but it would be extremely difficult for terrorists to breach the security cordon. It is possible that a jumbo jet could crash into a reactor or a nuclear pond of used reactor cores, but, again, security against such an incident is extremely high. Recently published results of computer and engineering studies suggest that the construction of most reactors would sustain a direct hit from a commercial aircraft flying into a reactor at less than 300 mph. However, some scientists question these findings.

Most people are aware of the reactor accidents at Three Mile Island in Pennsylvania and Chernobyl in Russia. The amount of radiation released from Three Mile Island was small indeed, and no radiation injuries resulted.

The Chernobyl reactor incident resulted because several safety systems were bypassed while a set of experiments with the reactor were performed. There were two explosions, with fires and meltdown of the reactor core, leading to serious widespread contamination of the environment.

The early phase of the accident had the following results:

- 237 persons were hospitalized
- 134 persons had acute radiation syndrome
- 28 persons died within the first 3 months
- 2 persons were killed in the initial explosion
- 1 person died of heart failure
- 250,000 persons were permanently evacuated from the area

---

**TABLE 10. Classification: nuclear sabotage and nuclear weapons fallout**

<table>
<thead>
<tr>
<th>Sources</th>
<th>Americum</th>
<th>Californium</th>
<th>Cesium 144</th>
<th>Cobalt 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear reactor sabotage fallback</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improvised nuclear device and nuclear weapon</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

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The primary radioactive isotopes responsible for health problems were $^{137}$Cs and iodine 131. Considering the gravity of the accident, it is commendable that the response team actions led to low overall mortality.

**Improvised nuclear device (Table 10).** An improvised nuclear device, if successful, could produce a nuclear yield similar to that of Hiroshima and Nagasaki, with release of radiation, blast, and thermal pulses together with significant radioactive fallout. Construction of such a device would be difficult because of sophisticated engineering and expertise required. In reality, a terrorist organization might be able to produce a partial yield, producing less effect. The conventional explosive would detonate and blow the device apart, resulting in environmental contamination with weapons material, such as plutonium or uranium.

**Nuclear weapon.** The probability of stealing a nuclear weapon in the western world is remote because of high security. However, a Russian general has stated publicly that 50 to 100 nuclear weapons with 1 kiloton rating are unaccounted for in the former Soviet Union. These weapons are potential “suitcase bombs,” and represent an increasing threat.

The consequences within the first minute of detonation of a 1 kiloton nuclear weapon are as follows:

- Blast range would reach 400 yd
- Thermal radiation would reach the same distance as the blast
- Nuclear radiation, that is, gamma particles and neutrons, would reach half a mile

Radioactive fallout could produce high exposure rates up to half a mile. The rule of seven applies. After 7 hours the dose is reduced by one tenth, after 49 hours ($7 \times 7$) the dose is reduced by another tenth, after 343 hours ($7 \times 7 \times 7$) the dose is reduced by another tenth, and so on. From this arises the concept of sheltering for a 2 weeks.

The electromagnetic pulse, that is, a high aerial burst, would result in damage to solid-state electronic equipment, such as hospital solid-state equipment.

<table>
<thead>
<tr>
<th>Cesium 137</th>
<th>Curium</th>
<th>Tritium</th>
<th>Iodine 131</th>
<th>Plutonium 239</th>
<th>Porion</th>
<th>Strontium 90</th>
<th>Uranium</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

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defibrillators, electrocardiograph machines, and ventilators, among other equipment.

**Radiation Cellular Damage**

The basic building block of all tissue is the cell. Damage to the main components of the cell, namely, cell membrane, complex proteins, and, especially, DNA, can lead to serious malfunction or even death of the cell. The chemical damage caused by free radicals is immediate, $10^{-10}$ seconds (Fig 1).

The mechanism of damage is via two pathways: the direct pathway (20% of the damage) and the indirect pathway (80% of the damage). The main target within the cell is the chromosomal DNA. In the direct pathway, single-strand or double-strand breaks occur in chromosomal DNA, which in some circumstances can be lethal to the cell. In the indirect pathway body water is ionized, with hydrogen ions and hydroxyl ions. Hydroxyl ions cause the damage to DNA. In some cases this damage can be repaired or modified, but in some instances is beyond repair.

Biologic expression of this damage at the cellular level is noted in seconds to hours; clinical expression can take hours to years. With high acute doses, ARS can be expressed within hours. With lower doses that are not capable of producing ARS, and even with very low doses, there is the probability of cancer after 20 to 30 years. Other problems that can be produced weeks to months after exposure include cataract, from an acute dose to the lens of the eye of 200 rem. Neutrons are more potent in producing this effect.

Effects on some fetuses were demonstrated in the survivors of Hiroshima and Nagasaki who received a dose of more than 50 rad. Birth
defects included low birth weight, small head circumference, and mental retardation. Hypothyroidism and infertility have also been associated with acute doses of radiation.

**Acute Radiation Syndrome**

To understand ARS two concepts need to be discussed, LD$_{50/60}$ and cell death.

Our senses cannot detect radiation. After atomic bombs were dropped on Hiroshima and Nagasaki, resulting in deaths and horrific injuries, experiments were carried out on animals to determine the required lethal dose to kill 50% of the animals in a known time, for example 30 days. This is known as LD$_{50/60}$, or the radiation dose that will kill 50% of the animal population within 30 days. The lethal effect depended on health, age, environment, and health of the various animal species, and varied from species to species. In human beings, LD$_{50}$ takes longer to express; therefore LD$_{50/60}$, that is, lethal dose required to kill 50% of the population within 60 days, is used. To determine lethal dose in human beings, only data from persons who died as a result of radiation accidents can be used, and the total number over the last 50 years is approximately 130 persons. Therefore LD$_{50/60}$ for human beings is expressed as the range, and is 250 to 450 rad.

Cell death is also an important consideration. Radiation-related cell death occurs at the dose required to stop cell division without killing the cell outright. A much lower dose is required to stop cell division than to kill the cell outright. Why is this important? Consider, for example, the hematopoietic system, and a red blood stem cell. That one stem cell is capable of producing more than a million red blood cells. By stopping that one stem cell from dividing over the long term, there is loss of more than a million red blood cells. The importance of this is that a sublethal dose produces this effect. Therefore, when considering the acute effects of radiation, we are concerned with rapidly dividing cell populations. Two important organ systems with rapidly dividing cell lines are the hematopoietic system and the GI tract.

ARS follows a predictable course over a few hours to several weeks after exposure to ionizing radiation. The interval depends on dose; the higher the dose the shorter the interval before manifestation of clinical signs and symptoms. The most important factors in producing ARS are:

- High dose
- High dose rate
• Penetrating radiation
• Whole-body exposure

Other factors that should be considered include sex, age, existing medical conditions, and genetic issues. The radiation source, whether radioactive isotope, industrial or medical application, weapon, or nuclear reactor, does not matter. If the dose is high enough, all will produce the same effects.

**Signs and Symptoms**

Signs and symptom of ARS occur in four distinct phases: prodome, latency, illness, and recovery or death.

**Prodromal phase (Table 11).** Onset is related to total dose of radiation received, and can be minutes to hours after exposure. Signs and symptoms, including nausea, vomiting, and anorexia, may last for 2 to 4 days with doses below approximately 500 rad, but may persist with higher doses. After very high doses of radiation, additional symptoms such as prostration, fever, respiratory problems, conjunctivitis, erythema, and increased excitability may develop. Development of gastrointestinal symptoms within 2 hours of exposure portends a serious and usually fatal outcome (Table 12).

**Latent phase (Table 13).** With doses of about 200 to 300 rad, signs and symptoms regress after 2 to 4 days and a latent period develops, which lasts 2 to 3 weeks. As the dose increases the latent phase becomes shorter. During this time critical cell populations, namely, lymphocytes, leukocytes, and platelets, decrease as a result of bone marrow insult. Higher doses affect the gastrointestinal cells, leading to gastrointestinal syndrome. At very high doses there is no latent phase.

**Illness phase (Table 14).** During this phase overt illness develops, which may be characterized by nausea, vomiting, bleeding, diarrhea, and other symptoms.

**Recovery or death phase.** Recovery or death follows the illness phase. Recovery can take weeks or months. If the dose of radiation has been high enough, death ensues.

Whole-body exposure to doses of 100 to 800 rad will produce hematopoietic syndrome; doses between 800 and 3000 rad will produce gastrointestinal syndrome; and doses of more than 3000 rad will produce cardiovascular–central nervous system syndrome.

**Hematopoietic syndrome.** The hematopoietic system exhibits the first indication of severity of radiation exposure, with rapid decline of the lymphocyte cell line, and decline in number of granulocytes, platelets,
thrombocytes, and reticulocytes (Fig 2). The systemic effects lead to immune system dysfunction, increased infectious complications, anemia, and hemorrhage, and impaired wound healing.

Initially, absolute lymphocyte count is crucial, and should be measured every 4 to 6 hours for the first 48 hours and an Andrews curve plotted. Average lymphocyte count is about 2500 cells/mL. If total lymphocyte count is greater than 1200 cells/mL, it is unlikely the patient has received a lethal dose of radiation. Cell count between 300 and 1200 cells/mL indicates significant exposure. The patient should be hospitalized and isolated with barrier protection. Lymphocyte count less than 300 cells/mL

| TABLE 11. Prodromal phase: approximate ARS degree and dose |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| **Signs and symptoms**          | **Mild (1–2 Gy)** | **Moderate (2–4 Gy)** | **Severe (4–6 Gy)** | **Lethal (>8 Gy)** |
| Vomiting                        |                  |                  |                  |                  |
| Onset                           | ≥2 h             | 1–2 h            | <1 h             | <10 min          |
| Incidence (%)                   | 10–50            | 70–90            | 100              | 100              |
| Diarrhea                        | None             | None             | Mild             | Heavy            |
| Onset                           | —                | —                | 3–8 h            | <1 h             |
| Incidence (%)                   | —                | —                | <10              | ~100             |
| Temperature                     | Normal           | <38.5°C          | Fever            | High fever       |
| Onset                           | —                | 1–3 h            | ≥38.5°C          | <1 h             |
| Incidence (%)                   | —                | 10–80            | 1–2 h            | 100              |
|                               |                  |                  | 80–100           |                  |
| Headache                        | Slight           | Mild             | Moderate         | Severe           |
| Onset                           | —                | —                | 4–24 h           | 1–2 h            |
| Incidence (%)                   | —                | —                | 50               | 80–90            |
| Level of Conscionsness          | Normal           | Normal           | Normal           | Unconscious      |
| Onset                           | —                | —                | —                | for sec-min      |
| Incidence (%)                   | —                | —                | —                | 100 at ≥50 Gy    |

ARS, Acute radiation syndrome.
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<table>
<thead>
<tr>
<th>TABLE 12. Prodromal phase predicts survival prognosis with ARS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prognosis</strong></td>
</tr>
<tr>
<td>Survival likely (probable)</td>
</tr>
<tr>
<td>Survival possible</td>
</tr>
<tr>
<td>Survival unlikely (improbable)</td>
</tr>
</tbody>
</table>

ARS, acute radiation syndrome; N/V, nausea and vomiting.
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is classified as critical, and warrants consideration of use of colony-stimulating factors (CSF) or stem cell transfusion. These important decisions are usually made by a hematologist. Although lymphocyte count decreases rapidly in the first 48 hours after exposure, neutrophil count initially increases. This is known as the steroid trauma response.

**Gastrointestinal system.** The classic symptoms of gastrointestinal syndrome, seen with doses greater than 800 rad, are nausea, vomiting, and diarrhea. Damage is to the specialized epithelial cell lining of the small intestine. The time of onset of vomiting and diarrhea is important; vomiting in the first 2 to 6 hours is suggestive of a very high dose. Vomiting and diarrhea can lead to fluid loss and opportunistic infection, which lead to septicemia as a result of loss of integrity of the villi that line the small intestine and act as a barrier. Persistent fever and bloody diarrhea are serious signs. Death can occur within 1 to 2 weeks.

---

**TABLE 13.** Latent phase: approximate ARS degree and dose

<table>
<thead>
<tr>
<th>Signs and symptoms</th>
<th>Mild (1–2 Gy)</th>
<th>Moderate (2–4 Gy)</th>
<th>Severe (4–6 Gy)</th>
<th>Lethal (&gt;8 Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epilation (hair loss)</td>
<td>None</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Complete</td>
</tr>
<tr>
<td>Onset (d)</td>
<td>—</td>
<td>≥15</td>
<td>11–21</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Lymphocyte count on day 6 (10^9 cells/L)</td>
<td>0.8–1.5</td>
<td>0.5–0.8</td>
<td>0.3–0.5</td>
<td>0.0–0.1</td>
</tr>
<tr>
<td>Latency phase duration (d)</td>
<td>21–35</td>
<td>18–28</td>
<td>8–18</td>
<td>0</td>
</tr>
</tbody>
</table>

*ARS, acute radiation syndrome.*

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**TABLE 14.** Illness (critical) phase: approximate ARS degree and dose

<table>
<thead>
<tr>
<th>Signs and symptoms</th>
<th>Mild (1–2 Gy)</th>
<th>Moderate (2–4 Gy)</th>
<th>Severe (4–6 Gy)</th>
<th>Lethal (&gt;8 Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onset (d)</td>
<td>21–35</td>
<td>18–28</td>
<td>8–18</td>
<td>0</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Infection</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bleeding</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Platelet count (10^9/L)</td>
<td>60–100</td>
<td>30–60</td>
<td>25–35</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Shock</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Coma</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Lethality (%)</td>
<td>0</td>
<td>0–50</td>
<td>20–70</td>
<td>100 by 1–2 wk</td>
</tr>
<tr>
<td>Onset (wk)</td>
<td>N/A</td>
<td>6–8</td>
<td>4–8</td>
<td>Day 1</td>
</tr>
</tbody>
</table>

*ARS, Acute radiation syndrome.*

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A word of caution is needed. Be aware of psychological nausea and vomiting. This has been recorded after accidents in which people thought they had been irradiated.

Cerebrovascular–central nervous system syndrome. There is no recovery from cerebrovascular–central nervous system syndrome, which results after doses of 3000 rads or greater, most probably due to microvascular leaks within the brain. Early vomiting and diarrhea occur within minutes. Confusion, disorientation, convulsions, cerebral edema, and coma tend to develop. In addition, hyperthermia develops, and patients usually die within a few days.

Local Radiation to Skin

Most victims of irradiation do not receive whole-body exposure, only partial body exposure, because part of the body is shielded. Type of skin lesion produced in ARS is a good indicator of dose (Table 15). Skin lesions include epilation (loss of body hair), erythema, dry desquamation, moist desquamation, and necrosis.

It is important to remember that patients may not come for treatment on the day of exposure. In two serious world radiation accidents resulting in contamination and exposure, the accidents were not recognized for 15 and 17 days, respectively.

Epilation. Epilation is loss of body hair, on the arms, legs, chest, and so on. To produce epilation requires a dose of 300 rad (3 Gy). Hair loss is usually not apparent for 17 to 21 days after exposure.

Erythema. Late erythema develops 2 to 3 weeks after exposure. The dose required is 300 rad (3 Gy).
Early erythema, which may appear in a few hours, indicates a dose in the region of 600 rad (6 Gy). Note that sometimes early erythema resolves, only to recur later. Therefore photographs should be obtained to record erythema. Note that erythema occurring within a few minutes is most probably due to a chemical contaminant, not irradiation.

**Dry desquamation.** Dry desquamation is dry peeling of the skin. The dose required to produce this effect is in the region of 1000 rad (10 Gy). Expression normally takes 2 to 4 weeks.

**Wet desquamation.** Wet desquamation results in formation of small blisters or large bullae. The dose required to produce small blisters is in the region of 1500 rad (15 Gy), and for large blisters is greater than 2500 rad (>25 Gy). Appearance of blisters can take 2 to 8 weeks, dependent on dose.

**Necrosis.** Necrosis results with a dose greater than 5000 rad (>50 Gy), and may not be demonstrated for a few days to months.

---

**TABLE 15. Local radiation injury**

<table>
<thead>
<tr>
<th>Skin lesions</th>
<th>Dose (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epilation (hair loss)</td>
<td>3</td>
</tr>
<tr>
<td>17–21 d</td>
<td></td>
</tr>
<tr>
<td>Erythema (redness)</td>
<td>6</td>
</tr>
<tr>
<td>Early (initial)</td>
<td></td>
</tr>
<tr>
<td>Within hours, not minutes</td>
<td></td>
</tr>
<tr>
<td>Within minutes implies chemical burn</td>
<td></td>
</tr>
<tr>
<td>≤24–48 h</td>
<td></td>
</tr>
<tr>
<td>Examine hourly for 24 h</td>
<td></td>
</tr>
<tr>
<td>Take photographs and note time</td>
<td></td>
</tr>
<tr>
<td>Latent LRI</td>
<td></td>
</tr>
<tr>
<td>No erythema</td>
<td></td>
</tr>
<tr>
<td>2 d to 2–3 wk</td>
<td></td>
</tr>
<tr>
<td>Later (second or main)</td>
<td></td>
</tr>
<tr>
<td>Onset ≥2–3 wk</td>
<td></td>
</tr>
<tr>
<td>Dry desquamation (peeling skin)</td>
<td>10</td>
</tr>
<tr>
<td>No blisters</td>
<td></td>
</tr>
<tr>
<td>Onset, wk 2–4</td>
<td></td>
</tr>
<tr>
<td>Moist desquamation (blistered, peeling skin)</td>
<td></td>
</tr>
<tr>
<td>Blister</td>
<td></td>
</tr>
<tr>
<td>Small blisters</td>
<td>&gt;15</td>
</tr>
<tr>
<td>Large blisters</td>
<td>&gt;25</td>
</tr>
<tr>
<td>Onset, wk 2–8</td>
<td></td>
</tr>
<tr>
<td>Necrosis (death)</td>
<td>50</td>
</tr>
<tr>
<td>Dead tissue</td>
<td></td>
</tr>
<tr>
<td>Gangrene</td>
<td></td>
</tr>
<tr>
<td>Autoamputation</td>
<td></td>
</tr>
<tr>
<td>Onset, days-months</td>
<td></td>
</tr>
</tbody>
</table>

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An accident involved a 28 Ci iridium 192 source that a patient put it in his back pocket. Several blisters developed within 5 hours, and one large bullae within 18 hours. Within 1 week a large necrotic ulcer developed on the right buttock. The dose at 1 cm depth was calculated at more than 50,000 rad (500 Gy).

Radiation Triage

It is important to remember that radiation contamination is not a medical emergency. Without treatment, a patient who received a very high dose of radiation would not die for days. Therefore the first priority is to stabilize the patient; only then is the contamination problem considered. ABCs (airway, breathing, circulation) always take priority.

Because degree of radiation injury will not be initially apparent, triage criteria must be based on associated injuries and complaints.

Patients who have received large doses of radiation will exhibit signs and symptoms (see Acute Radiation Syndrome).

Patients with trauma as well as irradiation are at increased risk for dying, compared with patients with a single insult. An acute dose greater than 200 rad (2 Gy) will result in burns, wounds, and fractures. Efforts must be made to close wounds, stabilize fractures, cover burns, and perform surgical stabilizing treatment, within the first 48 hours after injury. After 48 hours, surgery should be delayed for 2 to 3 months.

When radiologic survey and decontamination are complete, patients can be classified into three main groups: survival probable, dose less than 100 rad (1 Gy); survival possible, dose 200 to 800 rad (2-8 Gy); survival improbable, dose greater than 800 rad (>8 Gy).

**Survival probable.** Patients who will probably survive have few signs and symptoms; there may be nausea and vomiting, which generally subsides after a few hours. Once the initial complete blood cell count with differential has been determined and lymphocyte and granulocyte counts are acceptable, these patients can be sent home and given treatment on an outpatient basis. Ideally, blood should be obtained for chromosome analysis by a cytogenetics laboratory.

**Survival possible.** Patients who may survive have symptoms of nausea and vomiting that lasts about 24 to 48 hours, then recedes, and the latent phase begins. If the lymphocyte count drops below 50% of normal, barriers should be reversed and the patient managed by a hematologist. Bone marrow suppression will develop, which can lead to aplasia and pancytopenia, which can be fatal. Blood replacement products, antibiotic drugs, and antiviral and antifungal agents may be necessary. Colony-
stimulating factor or stem cell transplantation from bone marrow, peripheral blood, or fetal cord blood also may be required.

**Survival improbable.** The prognosis is poor in patients with acute whole-body exposure greater than 800 rad (8 Gy). After recent accidents, successful outcome was reported in patients who had received a dose of 800 to 1200 rad (8-12 Gy), insofar as hemopoietic syndrome was concerned; however, severe lung damage developed after a few months, and the patients died. In a mass casualty situation, such patients should be made as comfortable as possible, but survival is improbable.

**Hospital and Staff Preparation to Receive Irradiated and Contaminated Patients**

Emergency department staff is accustomed to treating chemical injuries on a weekly basis. Only slight modifications are required in the emergency plan. A nuclear health physicist must be added to the team, and will be invaluable with respect to dealing with irradiation and contamination. Train regularly as a team. Initially the nuclear health physicist might not be available; hence the need for training.

Ideally, the emergency department will be divided into dirty and clean areas. The floor of the dirty area should be covered with something like butcher’s paper, which is inexpensive and easily taped to the floor. Remove all unnecessary equipment from the dirty area; if there is not enough time, cover equipment with drapes. If x-ray films are required, use a portable x-ray machine.

Patient contaminated clothing should be double-bagged in polyethylene bags, labeled, and moved out of the emergency department to a place designated by the nuclear health physicist, because they would be a radioactive source in the department.

Protective clothing required by hospital staff in the emergency department is listed in Table 16.

Dosimeters should also be provided for each member of the staff. These include a quartz fiber dosimeter, worn at the neck of the surgical gown for easy access, and a thermoluminescent dosimeter, worn under the surgical gown. The nuclear health physicist can assist with these. The reason to wear dosimeters is that the body senses cannot detect radiation. The quartz fiber dosimeter can be read immediately, enabling control of individual doses.

Only commit staff when needed, and rotate staff as much as possible so the committed dose is shared. Golden rule: No eating, drinking, or smoking in a contaminated environment. Another important point that is often overlooked is to be sure that staff members use the rest room before
entering a dirty radiation environment, because they might be there for a long time.

Instrumentation is important (Table 17). Staff members should be able to use various instruments in an emergency, and to differentiate between alpha, beta, and gamma particles. Note that Geiger counters do not count alpha particles.

The following are some common instrument errors:

- Flat batteries (Instruments should be checked on a regular basis, and spare batteries should be available.)
- Forgetting to measure background each day
- Instrument in wrong switching position
- Reading the wrong scale
- Monitoring too fast
- Alpha monitoring while holding the probe too far away
- Putting a surgical glove over the alpha instrument probe (If alpha particles cannot penetrate a piece of paper, they certainly will not penetrate a surgical glove. However, a surgical glove may be placed over a beta gamma probe to protect it from contamination.)
- Switching off the audible alarm (Always use the instrument headphones provided, to prevent the patient from panicking.)

These error detectors should be checked regularly with appropriate staff training.

**Irradiated Contaminated Casualties**

Most probably there will be no warning that contaminated patients are arriving. In a terrorist event, the radioactive source will not be known, and there might be a large or small amount of contamination, although, in general, large amounts of contamination are noted at the incident site. Patients may have received a significant dose of radiation, but this depends on the source. It is important to realize that infection remains a
leading cause of death in radiation-exposed persons, because of profound injury to hematopoietic colonies, and subsequent immune compromise. Strict attention to infection control and promotion of host defenses is critical.

Patients may have been internally contaminated via ingestion, inhalation, a wound created by or exposed to radioactive materials, or external contamination in the absence of respiratory tract protection. Antidotes or chelating agents can be useful in altering absorption of radioactive materials in the GI tract, depending on toxicokinetics and solubility of the substance. Cesium is rapidly absorbed in the GI tract, whereas plutonium is not. Ion exchange resins such as Prussian blue, an investigational new drug (IND) can decrease GI uptake of certain radionuclides, such as cesium. Diethylenetriaminepentaacetic acid (DTPA; also an IND) can chelate heavy metal radionuclides, including radionuclides that are heavier than uranium, with the exception of neptunium. Calcium DTPA should be used in the initial 24 hours after exposure, followed by zinc DTPA. DTPA is available through Radiation Emergency Assistance Center/Training Center (REAC/TS) (telephone, weekdays, 865-576-3131; weekends and after hours, 865-576-1005). DTPA from nuclear medicine departments should not be used interchangeably with the above. The vials of DTPA provided by REAC/TS contained one gram of DTPA, whereas the dose of DPTA used in nuclear medicine is less. Dimercaprol can chelate arsenic and other elements, and can be considered for treating internal exposure from radioisotopes of those elements.
Consultation with REAC/TS or staff nuclear health physicist is recommended, depending on the exposure.

**General Medical Considerations**

Radiation events can be managed with modern techniques and technology.

1. It is important to have on staff or readily available a nuclear health physicist and to develop protocols to respond to a radiation victim. Skills-based training is essential to familiarize and enhance facility response. REAC/TS is operated by the Department of Energy, and is available 24 hours a day (telephone, 865-576-3131 or 865-576-1005).

2. Treat the patient before the poison! Treatment of serious medical problems takes precedence over radiation-related issues (Table 18). If the source of contamination is unknown, responders should wear protective clothing and respirators.

3. Follow ABCs (airway, breathing, circulation).

4. Remember that the two most radiosensitive systems are the hematopoietic and gastrointestinal systems.
   a. Gastroenteritis can result in significant fluid loss.
   b. Leukopenia can result in significant infection.

5. Enhance elimination of toxin.

6. Use the following measures, as appropriate:
   a. Infection control, such as antimicrobial agents and colony-stimulating factor (Table 19).
   b. Antidotes and pharmacotherapy, such as chelating agents or blocking drugs (Table 20).

7. System-specific and dose-specific intervention includes:
   a. Slit lamp examination to document cataracts.
   b. Liver function tests and coagulation studies.
   c. Determination of chromosome changes in lymphocytes. Such changes are considered highly sensitive indicators of radiation exposure, including as little as 10 rad.
   d. Use of Andrews Lymphocyte Nomogram or Modified USSR Classification for prognosis.

8. Decontaminate the patient.

The patient must be stabilized first; then, and only then, is the contamination problem considered. When taking a medical history it is important to ask whether the patient has recently undergone a nuclear medicine procedure. There has been the odd occasion in which such patients have been seen after radiation exposure. In addition, it is
important to ascertain any history of renal disease, because most drugs used to enable excretion of incorporated radioactive isotopes are excreted via the kidneys. After the patient is stabilized, monitoring for contamination can be started. If the clothing is contaminated, monitoring should be interrupted and the clothes carefully cut off. The clothes should carefully be placed in a double polyethylene bag, labeled with the patient’s name, and removed from the emergency department to a designated area. Then the patient’s body should be monitored completely,
with special attention to parts that were exposed, namely, the head, neck, and hands.

Decontamination of intact skin generally is achieved with soap and water, working from the periphery to the center. A few washings may be necessary to remove contamination. It is important to drape the area of concern with waterproof surgical sheets to prevent further spread of contamination. Save all washings for later analysis. If difficulty is encountered in removing contamination from intact skin, a light abrasive may be used, such as a cotton ball or makeup remover pad, or a mixture of ground corn and washing powder worked into a paste. If the skin becomes red and angry, stop the abrasive technique, cover the area with a dry dressing, and seek expert advice.

Mask around wounds with waterproof surgical drapes. Use sterile normal saline solution and a 50 mL syringe to irrigate wounds. Irrigation may be necessary several times. Save all washings from a wound, including any debris that has been removed. If the wound is still contaminated, refer to a surgeon. The object is to decontaminate to the background radiation level.

Hair can be decontaminated in two ways. If the patient is restricted to a gurney, the hair can be washed in the barber position over a sink. If the patient is ambulatory, the hair can be washed over a sink or in a shower.

---

**TABLE 20. Antidotes/common radionuclides**

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Antidote/Chelator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cesium 137</td>
<td>Potassium iodide blocks thyroid uptake</td>
</tr>
<tr>
<td></td>
<td>Prussian blue (ferric hexacyanoferrate) adsorbs cesium in GI tract; may enhance elimination</td>
</tr>
<tr>
<td>Plutonium 239</td>
<td>Aluminium hydroxide antacids may bind plutonium in GI tract</td>
</tr>
<tr>
<td>Radium 226</td>
<td>Ammonium chloride may increase fecal elimination</td>
</tr>
<tr>
<td>Strontium 90</td>
<td>Aluminium hydroxide antacids may bind strontium in GT tract; Ammonium chloride can acidify urine and enhance excretion</td>
</tr>
<tr>
<td>Tritium</td>
<td>Oral fluids will reduce biologic half-life from 12 to approximately 6 days</td>
</tr>
<tr>
<td>Uranium</td>
<td>Sodium bicarbonate renders uranyl ion less nephrotoxic</td>
</tr>
</tbody>
</table>

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Shampoo the hair once or twice; then shower the patient. The reason for shampooing the hair first is that it is the most likely site of contamination. Shampooing prevents contamination from trickling down the body, reducing the risk for contamination getting trapped in body hair or body crevasses. Ideally, this contaminated water should be saved, depending on the number of patients that require showering.

**Biological Sampling**

Nasals swabs, one from each nostril, must be obtained from every patient, noting the time post-incident. Obtain a throat swab, and save all sputum samples produced. Save all urine and fecal samples. Fecal samples are the most difficult to get patients to provide. Stress to the patient how important this sample is for measuring insoluble radioactive isotopes that have been ingested or inhaled. Obtain an initial wound swab, and save all irrigation fluid and swabs used, and any debris. Save all fluid used to decontaminate skin.

**Blood**

Obtain a complete blood cell count, with white blood cell differential, noting especially the lymphocyte and neutrophil count every 4 hours. If it is suspected that the patient has received a significant irradiation dose, send blood to a laboratory with capability for chromosome dicentric counting. For neutron count, send blood to a nuclear laboratory that is able to identify sodium 24.

In a terrorist event, it will not be known initially which isotope or isotopes must be dealt with. In such a situation, it is advisable to send the clothing of the first few patients, along with any initial wound dressings, to a nuclear laboratory for identification of the isotope or isotopes present. The hospital pharmacy should be informed of the isotopes present so that relevant drugs can be acquired. Remember that some drugs used in radiation emergencies are not easily available.

**Consideration of the Dead (Table 21)**

It is important to have a plan to facilitate the dead. Bodies that are contaminated should not be placed in the hospital morgue, because pathology facilities can be lost as a result of radioactive contamination. A temporary morgue must be set up. The ideal solution is a mobile chilling unit, as used in the food industry. Note that the requirement is a chilling unit, not a freezer unit. With freezing, some forensic evidence can be lost. Remember, we are dealing with a crime. The chilling unit could be strategically placed on the hospital grounds.
If corpses cannot be completely decontaminated, they must be buried. They cannot be cremated, because nuclear material cannot be destroyed with fire. Burial may be problematic within certain religion denominations; some religions insist that a body must be cremated within the first 24 hours of death. Therefore letters of dispensation from relevant religious heads should be in place.

Treatment of Radiation-Contaminated Injuries

Hospital staff should be prepared for any type of nuclear accident, including terrorist attack, nuclear reactor accident, or industrial source, to name a few. Regardless of the source, if the dose is high enough the same biologic effects will be produced.

Patients with radioactive isotopes incorporated in wounds, that is, radiation-contaminated injuries, require more specialized treatment. Specialists in hematology, oncology, radiation, and infectious disease should be consulted. Access to nuclear departments with whole-body monitors and other nuclear facilities will also be required.

Treatment of internal contamination is dictated by the patient’s current medical condition, medical history, biologic sample results, and whole-body monitoring results.

Medication administered depends on the isotope that is present. An excellent reference is Report No. 65, from the National Council on Radiation Protection and Measurements, and the Safety Series 47, from the International Atomic Energy Authority.

Conclusion

Every hospital specialty will be involved, in one way or another, in treatment of patients with irradiation injuries. The nuclear health physicist is a key member of the emergency team. For advice from deep radiation specialists, contact REAC/TS, operated by the Department of Energy, at Oak Ridge, Tennessee, which is the World Health Organization and International Atomic Energy Authority collaboration center. This center offers year-round care.

### TABLE 21. Care of the dead

- Put corpse in body bag
- Do not use hospital morgue
- Ideally, use refrigerator truck, not freezing truck
- Preserve forensic data
- Do not cremate contaminated bodies
  - Radioactive matter is not destroyed by fire
- Try to respect religious beliefs

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24-hour emergency service, and can be contacted by telephone (weekdays, 865-576-3131; weekends and after hours, 865-576-1005).

Addendum
This article is adapted from the Advanced Hazmat Life Support Provider Manual. Advanced Hazmat Life Support (AHLS), a 2-day continuing education program, held its first course in October 1999, and has grown into an international program. AHLS is based in Tucson, Arizona, at the University of Arizona Emergency Medicine Research Center, and is co-sponsored by the American Academy of Clinical Toxicology. AHLS trains medical personnel, including paramedics, physicians, nurses, pharmacists, and toxicologists, in medical management of persons exposed to hazardous materials, such as from nuclear, biologic, and chemical terrorism. Courses are offered throughout the United States and in Canada and Australia. For additional information and a listing of courses, check the AHLS website (www.ahls.org) or contact their international headquarters (telephone, 520-626-2305; e-mail, ahlsinfo@aemrc.arizona.edu).

References