Management of Ionizing Radiation Injuries and Illnesses, Part 1: Physics, Radiation Protection, and Radiation Instrumentation

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Ionizing radiation injuries and illnesses are exceedingly rare; therefore, most physicians have never managed such conditions. When confronted with a possible radiation injury or illness, most physicians must seek specialty consultation. Protection of responders, health care workers, and patients is an absolute priority for the delivery of medical care. Management of ionizing radiation injuries and illnesses, as well as radiation protection, requires a basic understanding of physics. Also, to provide a greater measure of safety when working with radioactive materials, instrumentation for detection and identification of radiation is needed. Because any health care professional could face a radiation emergency, it is imperative that all institutions have emergency response plans in place before an incident occurs. The present article is an introduction to basic physics, ionizing radiation, radiation protection, and radiation instrumentation, and it provides a basis for management of the consequences of a radiologic or nuclear incident.

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Ionizing radiation refers to radiation that is electromagnetic or particulate in nature and that has sufficient energy to cause ejection of an electron from an orbital shell of a target atom. This ejection creates charged particles or ions. (*Nonionizing radiation*—such as light, microwaves, and radiowaves—does not have sufficient energy to eject an electron from another atom.) Ionization of biologically important molecules (eg, DNA) can cause cellular death by means of apoptosis and mitotic catastrophe.[1] Ionizing radiation at higher doses can cause damage to actively dividing and undifferentiated cell types (eg, stem and progenitor cells in the bone marrow, gastrointestinal system, or skin). Damage to these relatively radiosensitive systems becomes clinically manifest in the acute radiation syndrome. Radiation injuries and illnesses are rare, and they carry significant morbidity and mortality. Therefore, physicians must develop a thorough understanding of these conditions before encountering 1 of these patients.

Taking into account the heightened awareness demanded by the current global security environment, all health care professionals (eg, physicians, nurse practitioners, physician assistants) should also be mindful of the threat of terrorists using radiation-based weapons such as radiologic exposure devices, radiologic dispersion devices, and various types of nuclear weapons.[2] Radiologic/nuclear (R/N) incidents may require health care professionals to care for overwhelming numbers of patients with ionizing radiation exposure. To successfully evaluate and treat patients exposed to ionizing radiation during a disaster scenario, health care professionals need to understand the basic science of what radiation is and of how radiation interacts with matter. Such concepts may, for example, help health care professionals make more informed decisions before ordering a radiographic examination or using a nuclear medicine modality. In the aftermath of an R/N incident, health care professionals need to know how to detect the presence of radioactive materials and quantify and identify them.

Whether by means of radiographic, radiologic, or radionuclide examinations, deliberate ionizing radiation exposure occurs on a daily basis, sometimes without substantial consideration for potential sequelae. In the past few years, Sodickson et al,[3] Fazel et al,[4] and Pearce et al[5] have drawn attention to the overuse of radiographic imaging and the potential negative health effects of repeated ionizing radiation exposure.

The current article provides an overview of radiation detection and identification equipment, with recommendations of the best use of the devices. Although specialists—nuclear medicine technicians, health physicists, and potentially radiation oncologists—will be the primary users of these devices during an emergency, health care professionals should nonetheless understand the underlying scientific principles of each device. The readings from these instruments will, after all, directly guide the treatment of patients.

The information in the current article—and in the 4 subsequent articles in this series[6-9]—is intended for health care professionals, as well as planners, Emergency Medical Service medical directors, and others who may respond to and care for patients during an R/N incident.

Physics of Ionizing Radiation

An *element* consists of a single atom that is identified by the number of positively charged *protons* in its nucleus.[10] For example, hydrogen has 1 proton in its nucleus, and therefore its atomic number (Z) is 1 (in atomic mass units [amu]). A negative electron orbits the nucleus, rendering the atom electrically stable. In larger, higher-Z atoms, *electrons* circle the nucleus in multiple *electron shells* or *orbits* (sometimes called *electron clouds*). The nucleus of an atom also includes *neutrons* (except in the case of hydrogen, which has 0 neutrons), which have approximately the same mass as protons but carry no charge. Electrons are very small particles in terms of mass, being about 1/1800 the mass of a proton or neutron, so they add little to the mass of an atom.

If a neutron is added to the hydrogen nucleus, deuterium, an isotope of hydrogen is formed.[11] In this instance, Z remains 1 to identify it as the element hydrogen, but the change in the number of neutrons changes the isotope of hydrogen. The mass number (A) is the sum of Z and the number of neutrons (N) (ie, $A=Z+N$).

Another example is the element uranium ($Z=92$). Uranium has a number of isotopes of interest, including those for which A is 233, 234, 235, and 238. Each of these isotopes corresponds to the same Z, identifying each as uranium and dictating its chemical behavior; however, each has different numbers of neutrons in the nucleus, 141, 142, 143, and 146, respectively. All isotopes of uranium are unstable or radioactive.

Radioactive Materials and Ionizing Radiation

The relationship between N and Z determines whether a material is unstable and therefore radioactive. As a radioactive atom disintegrates (decays), radiation is released in the form of electromagnetic energy or as particles. Radiation is called *ionizing* if the energy deposited in a target atom—also known as a *receiver* or *absorber*—can create ion pairs or a pair of charged particles.[12]

Energy Units of Measure

For ionizing radiation, the energy of the particular emission is measured in electron volts (eV) and is often expressed in kilo-electron volts (keV or 10^3 eV) or in mega-electron volts (MeV or 10^6 eV). These units express how much energy a particular radiation can deposit into an absorber. The *Table* provides examples of emis-

Table.
Common Radioactive Materials, Their Emissions, and Where They Are Used

Radioisotope	Emission and Energy	Where Used
Cesium-137 (Cs-137, ^{137}Cs)	0.611 MeV γ	Industry, industrial radiography, medical
Cobalt-60 (Co-60, ^{60}Co)	1.17 MeV γ and 1.33 MeV γ	Industry, industrial radiography, medical
Iridium-192 (Ir-192, ^{192}Ir)	0.468 MeV	Industry, industrial radiography, medical
Uranium-235 (U-235, ^{235}U)	4.679 MeV α	Military, power
Plutonium-239 (Pu-239, ^{239}Pu)	5.157 MeV α	Military
Radium-226 (Ra-226, ^{226}Ra)	4.78 and 4.6 MeV α	Commercial
Technetium-99m (Tc-99m,^{99m}Tc)	0.14 MeV γ used	Medical
Tritium (H-3, ^{3}H)	0.0186 MeV max β	Research, universities
Strontium-90 (Sr-90, ^{90}Sr) occurs with	0.544 MeV max β	Research, universities, medical
Yttrium-90 (Y-90, ^{90}Y)	2.25 MeV max β	

sions and energy associated with common radioactive materials.

Ionizing Radiation

Types of ionizing radiation vary depending on the radioactive material[13] emitting them:

- *Alpha* (α) *particles* consist of 2 protons and 2 neutrons. These particles carry a +2 charge, and they have energy of approximately 4 to 8 MeV.
- Usually associated with fission, or the splitting of the atom, neutrons are also emitted from the nuclei of some radioactive materials, such as californium-252 or americium-beryllium sources. Neutrons are emitted over a wide spectrum of energy but the neutrons of concern for medical purposes are usually approximately 1 to 20 MeV.
- *Electron beta* (β^-) *particles* are negatively charged particles equivalent to orbital electrons but are emitted from the nucleus. Beta particles are emitted along a wide spectrum of energy depending on the radioactive element. Thus, their energy is usually stated as a maximum energy or sometimes as a mean energy.
- *Positron beta* (β^+) *particles* are identical to β^- particles in mass. However, β^+ particles are positively charged. Shortly after emission they interact with an orbital electron in another atom. This interaction between a particle and its antiparticle results in the annihilation of both particles, thus converting their masses into electromagnetic energy.
- *Gamma* (γ) *rays* are electromagnetic energy emitted from the nucleus and have discrete energy levels, which aid in the identification of γ-emitting radionuclides.
- *X-rays*, which are also electromagnetic in nature, are emitted when electrons in an orbital shell lose energy when they drop to a shell of lower energy. The energy an electron loses when changing shells is equivalent to the energy of the x-ray emitted. X-rays generally have energy lower than that of gamma rays' energy. X-rays can also be produced in x-ray machines by means of *bremsstrahlung*, or *braking radiation*, created by slowing down electrons in a metal target.

Measurement of Radioactivity

The amount of a radioactive material is expressed in activity units. Several units for radioactivity or simply "activity" are used. One decay per second, or a disintegration per second (dps), is called a becquerel (Bq) in the Système International (SI). Because most quantities of radioactive materials may undergo up to trillions of disintegrations per second, it is more common to see units of megabecquerels (MBq, or 10^6 Bq), gigabecquerels (GBq, or 10^9 Bq), or terabecquerels (TBq, or 10^{12} Bq).

The conventional unit used in the United States is the curie (Ci), which is equivalent to 3.7×10^{10} Bq (37 GBq). Activity levels typically encountered in nuclear medicine are in millicuries (mCi or 10^{-3} Ci) or microcuries (μCi or 10^{-6} Ci). Some sources used in brachytherapy and a number of industrial applications have activities of many curies, up to tens or hundreds of curies.

Radiation Penetration and Shielding

Another important concept to radiation medicine is *linear energy transfer* (*LET*), which describes the ability of a particular radiation to deposit its energy along its path as it moves through another material. Linear energy transfer is usually measured in MeV/cm. The α particle is an example of a radiation that is very efficient at causing ionizations and is therefore called a *high-LET* radiation. However, β particles, γ rays, and x-rays are examples of radiation that are relatively inefficient at causing ionizations and are referred to as *low-LET radiation*.

The LET concept is related to the shielding requirements for a particular radiation. Because α particles are so interactive with other matter, they lose their energy very quickly. They can travel only a few centimeters in air, and they can be shielded with 1 sheet of paper. Because they are less densely ionizing than α particles, β particles can travel farther—up to a few meters in air—and are typically shielded using plastic, glass, or a thin layer of metal. Photons such as γ rays or x-rays are even less efficient at ionizing and can travel many meters in air. They likely interact in the electron cloud. Therefore, heavy, dense materials—ones with a high Z (ie, >88), such as lead—are effective shields against photons because the higher number of protons in the nucleus results in a large number of electrons circling it.

Unlike other particles, effective shielding of neutrons requires increased interactions with the nuclei of light atoms. Thus, material that is abundant in hydrogen, with its low Z, works best at shielding neutrons; for example, water and paraffin are excellent shields for neutrons.

Neutrons, unlike other forms of ionizing radiation, can make other materials radioactive. This effect is called *neutron activation*, and it occurs when the stable nucleus of an atom absorbs a neutron, thereby upsetting the neutron-to-proton ratio. *Figure 1* depicts the shield requirements for various types of ionizing radiation.

Figure 1.
The contamination survey meter, or Geiger-Müller detector (often called a Geiger counter). Most often, the detector consists of a tube contained within a pancake probe (right). Although design and appearance vary according to manufacturer, Geiger-Müller detectors are able to read ionizations by means of an inert gas placed within the tube.

Radiologic (or Physical) Half-Life

Time is the only means by which irradiated materials lose their radioactivity. *Biological half-life*—the time it takes for the body to remove one-half of a quantity[13] by ordinary removal mechanisms (eg, urination, defecation, sweating)—is well understood in the medical community. For radiologic materials, the time to decay to one-half of its original activity is called the *physical*, or *radiologic*, *half-life*. When both the biological and physical half-lives are factored in, a measure called *effective half-life* is derived. Effective half-life is always less than either the biological half-life or the physical half-life, although 1 type may be dominated by the other.

Exposure or Irradiation vs Contamination

Exposure or *irradiation*, for practical purposes, means being in the presence of ionizing radiation.[14] During an irradiation or exposure, no radioactive materials are physically transferred. On the other hand, *contamination* occurs when radioactive materials are transferred to another surface. *Internal contamination* occurs when radioactive materials are internalized by inhalation, ingestion, percutaneous (transcutaneous) absorption through normal skin, or via puncture (injection) wounds.

Radiation Absorbed Dose

Physicists use the unit roentgen (R in conventional units) or coulombs per kilogram (C/kg in SI units) to measure exposure. Exposure is defined as ionizations in air for a given radiation energy. When the radiation energy is deposited into matter, such as tissue, it is referred to as the *radiation absorbed dose*. As stated above, the energy of the various ionizing radiation represents the energy that can be imparted to another material. The conventional unit for radiation absorbed dose is rad. One rad is equal to 100 erg (a unit of energy and mechanical work) of energy deposited into 1 g of absorber. The SI unit for absorbed dose is the gray (Gy) and is equal to 1 joule (J) of energy deposited into 1 kg of absorber. Because $1\ \text{J}=1\times10^{7}$ erg and $1\ \text{g}=1=10^{-3}$ kg, the conversion is simply a factor of 100 (1 Gy=100 rad; 1 rad=0.01 Gy).

Equivalent Dose

Another concept used to assess the long-term risk of biological damage is *equivalent dose*. This measure is derived from the product of absorbed dose in rad or gray and a *radiation weighting factor* (W_R) for the radiation being observed. The W_R compares the biological damage and resulting risk of any type of radiation to a standard. The conventional unit for equivalent dose is the *roentgen equivalent human* (rem). The SI unit of measurement is the sievert (Sv) (1 Sv=100 rem; 1 rem=0.01 Sv).

For x-rays and γ rays, W_R is 1, making the rad equal to the same dose in rem (also true for gray to sievert). Also, β particles also have a weighting factor of 1. Essentially, because of the way in which α particles transfer energy, the biological damage and resulting risk is 20 times that of the same dose delivered by a γ ray. Therefore, for α particles, the W_R is 20. Because α particles cannot penetrate the skin, prevention of internal contamination with α-emitting radionuclides is important for radiation protection. For neutrons, the W_R ranges from 5 to 20 depending on the energy of the neutron.

Radiation Protection

Protection from external radiation exposure is related to the principle of *ALARA*, or attempting to keep exposures *as low as reasonably achievable*. This principle underscores the 3 main actions to be undertaken during an R/N incident: (1) decreasing the amount of *time*, (2) increasing the amount of *distance* and (3) *shielding* between a radiation source and people.[13] Patients should be protected from radioactive materials and ionizing radiation in the same manner with which health care professionals protect themselves, that is, by wearing appropriate personal protective equipment such as gloves, gowns, face shields, and respiratory protection devices. Health care professionals should pay particular attention to clothing and surfaces when treating a contaminated patient. Proper, timely removal of a patient's clothing—taking care to avoid aerosolizing radioactive powder—can reduce substantial amounts of contamination. Radioactive material can be spread from 1 surface to another, therefore efforts should be made to control contamination at the source. We stress the "reasonably achievable" aspect of ALARA: although decontamination is a priority, it should not delay acute medical care.

Instrumentation

Protection of responders, health care workers, facilities, and patients is an absolute priority for the delivery of medical care after an R/N incident. Instrumentation that detects, quantifies, and identifies ionizing radiation is then needed to provide a greater measure of safety for workers when working with radioactive materials or casualties. Physicians must understand the basics of radiologic instrumentation—and of each device's readings—in order to manage the medical treatment setting. Because any health care professional could face a radiation emergency, it is imperative that R/N response plans are in place before an incident occurs. Hospital-based physicians should seek out health physics/radiation protection personnel, nuclear medicine personnel, and the hospital's radiation safety officer for guidance regarding the selection and use of radiation instruments. Office-based physicians, who may not have immediate access to nuclear medicine or radiation safety personnel, should nonetheless have a cursory understanding of the differences between instruments. Resources with appropriate instrumentation, even in these noninstitutional settings, should be sought before an incident occurs. (It is beyond the scope of the present article to give more than an overview of radiation instrumentation.)

There are 4 basic types of instruments used for radiation protection and contamination control:

- *Contamination survey meters* are used for radiation surveys of equipment, facilities, or personnel. They measure the amount of the radionuclide activity present on a surface.
- *Dose rate meters* measure the exposure of a given area to a radiation field, including the interactions with the radiation, number of ionizations occurring, and relating this information to dose rate (energy transfer). These measures are important for personnel protection in the hospital and in the field.
- *Dosimeters*, which measure an accumulated radiation dose, are usually static devices that must be sent to special laboratories to determine the amount of radiation dose over time. Some dosimeters can measure accumulating dose in real time, and they use either analog or digital display screens.
- *Radionuclide identification instruments*, such as γ spectrometers, are used for identification of x-ray or γ-ray emissions. Other special instruments must be used for emissions of α or β particles.

Contamination Survey Meter

The most basic of ionizing radiation detection instrumentation is the contamination survey meter, or *Geiger-Müller* (*GM*) detector. (The *GM* refers to the original tube's designers, and the instrument is often called a *Geiger counter*.) Most often, a GM detector consists of a tube contained within a *pancake probe* (*Figure 1*). Although design and appearance vary according to manufacturer, all detectors do essentially the same thing: reveal ionizations by means of an inert gas within the instrument.[15] This gas generates ion pairs, which in turn are converted and levels of which are displayed on screen in either analog or digital form (*Figure 2*).[16] Most detectors also emit a series of audible clicks or beeps that correspond to these levels. Depending on their configurations, GM detectors can be used for both contamination measurements and dose rate measurements. Readings from this instrument will be used to help determine the extent and magnitude of radioactive contamination. Radioactive contamination will have to be

Figure 2.
An analog display on a Geiger-Müller detector, with audio indicator and multiplier switch.

managed by the treating physician, especially if there is the potential for internal contamination, which may enter the body via a contaminated wound or a nasal passage.

The *pancake probe* is used primarily to detect radioactive contamination. It can be used to monitor for α-, β-, or γ-emitting radionuclides. However, care should be taken when using this probe for α contamination. Because α particles have a high mass and lower speed than other types of radiation, they can travel only a few centimeters in air. Thus, they are easily absorbed by materials and can be easily shielded against.

Note the reading is displayed in counts per minute (cpm). Activity is measured in disintegrations per minute (dpm), disintegrations per second (dps, or Bq), or curies.

A GM detector cannot measure every disintegration that occurs, but rather detects a percentage of them. Because various radiation types with their respective energy levels have differing potentials for creating ionization within the GM tube, the interpretation of cpm into dpm is dependent on knowing what the radioactive material is. In short, the instrument's efficiency is limited to detection of disintegrations. A physicist should be consulted for interpretation of the readouts.

The following items need to be checked before a survey meter (pancake probe) is used:

- overall condition of the instrument (no visible instrument damage, and readouts and sounds are functioning),
- calibration,
- freshness of batteries,
- response to a radiation check source.

Operators should also take a background reading of the sensitive side of the instrument away from the area being surveyed. As a general rule, a person is considered contaminated when the reading is 2 to 3 times the normal background level (typically 20 to 40 cpm). A variety of sources contribute to background radiation levels, including natural sources (eg, naturally occurring radioactive materials in the earth's crust), sources used in medicine (eg, technetium-99m, radioactive iodines), medical uses of ionizing radiation (eg, x-rays), industrial uses of radioactive materials (eg, industrial radiography, industrial irradiators), and radiation from outer space.

When patients initially present with symptoms, they should be quickly surveyed to determine if they are contaminated, and if so, to what magnitude. If contamination is detected, the patient's clothing should be removed, placed in a plastic bag, labeled, double-bagged, and then moved to a storage area for later disposition. Keep in mind that the clothing will provide a good sample for isotope identification. Surveys of personnel, facilities, and equipment need to be thorough and methodical, gathering readings from all surfaces. To perform a proper confirmatory survey, the probe should be held about ½ in away from the person or the object and should be moved no faster than 1 to 2 in per second. If an increase in count rate is observed or heard, the detector should be held over the area with the elevated reading for approximately 10 seconds to ascertain the contamination level. Then, the naked patient's body area should be surveyed in the following order: open wounds, facial orifices, intact skin. Decontamination priorities should follow the same order.

When taking readings with a pancake probe, it is important to be aware of the common mistakes. One should make sure the unit is on; make sure that sound is switched to on if sound is being used to locate contamination; and also make sure the correct *multiplier* (*range selector*) is selected. An analog readout requires changes in the multiplier to take accurate readings; therefore, care must be taken to use a multiplier that will give a correct measurement. Conversely, digital readouts already factor in the multiplier by means of autoranging, but one should always verify which units of measure are being displayed because on some detectors the units can change automatically. One should also pay attention to the distance from the surface and survey speed. Although many meter faces show dose rates in milliroentgens per hour (mR/h) when used in conjunction with pancake probes, GM detectors are not well suited to measure dose rates.

Health care professionals need not know the intricacies of all detector types. There is no "one size fits all" for radiation detection, and each detector type has its own specific limitations. We recommend that, in addition to learning the actions and limitations of detectors, health care professionals communicate with nuclear medicine personnel, institutional physicists, or other outside experts to confirm the location and type of instrumentation available for use during an R/N incident.

Dose Rate Meter

Despite a similar appearance, a *dose rate meter* has a very different function from a contamination survey meter. This instrument measures the rate at which irradiation or exposure is occurring. Therefore, its primary function is to protect personnel before contamination. Often, the detector is internal to the meter housing. The meter housing is often metal, which will shield α and β particles, so this style of dose rate meter can be used only for detection of x-rays or γ rays. This is usually true for GM and sodium iodide detectors. Some instruments, such as ion chambers, have a window in the metal box that can be opened to enable detection of β particles.

The dose rate meter will be used in hospital or in the field by emergency medical workers and fire and hazardous materials personnel. Field personnel can use these instruments to help determine the risk from radiation to personnel entering an area.

For patients who have been exposed to an R/N incident, medical and surgical needs take priority over radiologic concerns. Once unstable medical and surgical conditions have been controlled, radiologic conditions can be addressed, though physics personnel may be allowed to proceed with surveys of patients as long as they do not interfere with emergency medical care.

Identification Instrumentation

Ideally, one should be able to identify a toxicant and measure how much of it is present. Radioactive materials and ionizing radiation are no different. A GM detector, which is easy to use, will help to determine the type of radiation being emitted, and whether α, β, or γ in nature. Starting with the pancake probe approximately ½ in away from the surface being surveyed, move the probe away from the area. If the counts fall off dramatically and are close to background within a few inches, an α emitter is probably present.

If the counts persist, turn the detector over and measure again at approximately ½ in, using the back of the pancake probe as a shield. If the counts fall away to near background, the material is probably a β emitter. If a substantial amount of radiation still passes through the detector, then the material is probably a γ emitter. Of note, because of the presence of multiple types of radiation, one may not be able to isolate the exact emitter type.

Nonetheless, these techniques may help an operator to form an approximation.

If one can determine the type of radiation, risk evaluations can be made. For example, there is greater risk of internal contamination with an α emitter than with a γ emitter of the same activity. The exact identity of the α emitter must then be urgently sought with greater speed than for a γ emitter. Some assumptions can be made, however, on the basis of context and history. For example, one might assume that if a γ emitter is present in an industrial environment, one might more likely be dealing with radioactive cesium, cobalt, or iridium. The *Table* lists locations where some commonly encountered radioactive materials are found.

Each isotope emits γ rays in a unique energy pattern. A γ spectrometer can be used to identify the radionuclide by determining the energy of the γ emission. Some of these devices are very sophisticated and accurate, but they are mainly used in laboratories and are not portable. Others are portable but may lack the high-energy resolution of the laboratory models. All of these instruments can be quite expensive. Whether in a laboratory setting or in the field, a spectrometer's operations, as well as interpretation of its readings, requires considerable training and experience; therefore, physicians would not be likely to use one. Other types of laboratory instruments that may be used for identifying radioactive materials include liquid scintillation counters for β emitters and α spectrometers for α emitters. These laboratory identification instruments involve incredibly time-consuming processes, sometimes several weeks, but will still likely be used for the analysis of excreta to help determine internal dose.

Figure 3 lists facilities with these types of equipment. Health care professionals should be aware of these resources before an R/N incident.

Dosimetry

Dosimetry is required to monitor personnel doses during an R/N incident. A dosimeter is designed to measure accumulated dose. The function and design are variable, and the instrument is often attached to the outer layer of clothing, just above the waist. Functionally, dosimetry can be divided into real time and delayed. Delayed reading dosimeters cannot be read immediately. They must be sent to a special laboratory for analysis. Examples are optically stimulated luminescent dosimeters and thermoluminescent dosimeters.[17(pp156-159)] Other forms of dosimetry are the simple film badges that use x-ray film and that have been used extensively in hospital settings over many decades.

Electronic dosimeters are available from many manufacturers and can provide real-time dose rate measurements, calculate total accumulated dose, and have programmable alarms that indicate when radiation has reached a particular preset level. Older pocket dosimeters are analog, with no batteries required, and display an accumulated dose in real time at one end by means of a needle moving across a meter.

Often, the number of available dosimeters does not match the number of responding personnel. In that case, health care professionals should make sure to have a representative sample of the personnel wearing a dosimetric reader or badge. Another approach is to post a dosimeter in the area also to provide more information on dose rates during an incident. The best approach is to discuss this topic with institutional physics personnel and decide how a facility will handle external personnel dosimetry. These

State radiation departments
Nuclear power plants
Local hazardous materials disposal and removal sites
Civil support teams in the National Guard for each state
US Department of Energy facilities
The US Department of Energy's 10 regional Radiological Assistance Program (RAP) teams

Figure 3.
Facilities that can assist health care professionals during a radiologic or nuclear incident.

personnel are usually stationed in the nuclear medicine, radiology, or safety department. By law, every hospital that uses radiologic materials has a radiation safety officer, and he or she may be of assistance.

Scenario

Individuals at a nearby radiologic facility are working in a contaminated area when the scaffolding collapses. Fortunately, several of the workers escape serious injury; however, 2 patients arrive at the emergency room with non–life-threatening injuries. The first patient is determined not to be contaminated and is transferred to another part of the department for management of his injuries. Unfortunately, the second individual tore his protective clothing, and as a result is potentially contaminated with radioactive materials. The hospital is made aware of this incident and initiates its R/N incident response plan. On arrival, a medical assessment is performed to verify the patient's status. Concurrently, a radiologic survey is performed and contamination is verified. The patient's clothes are removed, bagged, and saved as a sample for further analysis. Radiologic surveys are performed and contamination is found on several areas of intact skin and 1 laceration is contaminated. Although medical decisions are of primary concern, the physician decides the injury is not serious enough to require immediate attention.

Medical care always takes priority over radiologic concerns. The patient's condition is stable, so the health care professionals next address radiologic issues and proceed with decontamination. As previously mentioned, areas that more easily allow entry of radioactive materials into the body (eg, wounds, facial or body orifices) are the first priority, so the lacerations are monitored to determine initial contamination levels, and the potentially contaminated body area is draped according to proper contamination control precautions. *The Medical Aspects of Radiation Incidents*[14] provides guidance for assessing contaminated wounds. On completion of the first decontamination process, the drapes are removed and the area is monitored to assess the progress of decontamination. The patient's wound is still substantially contaminated, so the process begins, again, with the intent of lowering the contamination levels in the wound. Once the levels are sufficiently low—with a realistic goal of approximately 2 to 3 times the natural background for β or γ emitters—decontamination can begin in facial orifices and then on intact skin.

Facial orifices are the next priority. Nasal passages are swabbed, and the swabs are read by the GM detector. If obtained within an hour, one may assume that the amount of radioactivity in the nose represents 10% of what might have been inhaled. These swabs must be obtained within an hour of the initial exposure because the nasopharynx clears so rapidly. The Radiation Emergency Assistance Center/Training Site at the Oak Ridge Institute (http://orise.orau.gov/reacts/) should then be contacted to help determine the magnitude of inhalation and the potential for *decorporation*, which is the physiologic process of removing internal contamination from the body by means of particular drugs.[14] The use of radiologic instrumentation plays an important role in the initial assessment of patients and verification of decontamination progress. Before leaving a radiation patient treatment area, personnel in the area, as well as equipment that was used, must be surveyed for contamination and decontaminated as necessary.

Conclusion

Even if physicians are not experts in health physics or in the use of radiation instruments, they should be familiar with the basic response principles related to R/N incidents. There are many different types of radiologic instrumentation, and access to relatively simple instruments can be of great importance. Further field guidance can be found in the REAC/TS pocket guide, *The Medical Aspects of Radiation Incidents*.[14] In *Figure 4,* we have listed resources for further reading in basic radiation science.

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Figure 4.
Resources for further reading in basic radiation science.

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