Chapter 29

MEDICAL RESPONSE TO INJURY FROM IONIZING RADIATION

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INTRODUCTION

Military medical health care providers need to be familiar with the health effects of radiation exposure and the other devastating effects of a nuclear explosion or accident. At the same time that superpowers are dismantling nuclear bombs, smaller powers are building nuclear arsenals, and radiation exposure scenarios include those involving low-yield nuclear devices deployed by terrorists and accidents during transportation or dismantlement of weapons. Even without bombs, there is an increasing chance of radiation exposure from sources such as nuclear power plants, research facilities, and hospitals. The potential also exists for exposure from depleted uranium munitions; industrial, hospital, and research waste sites; and directed energy devices. Military medical preparedness is important to meet the operational challenges presented by these scenarios. Since the late 1940s, nuclear weapon proliferation has continued to pose a global threat and one for which military medical personnel must train and plan. This new operational environment requires a review of the US military's medical policies, equipment, and research requirements.

HISTORY OF NUCLEAR WEAPONS

In the United States, the development of nuclear weapons grew out of concern in the 1930s that Germany was developing a nuclear weapon. The start of World War II, with the Japanese attack on Pearl Harbor and the German and Italian declaration of war on the United States in December 1941, increased the impetus for the United States to develop its own nuclear weapon. The program to develop a bomb was under way by the fall of 1942. To supply the materials needed, the US government secretly started a massive project to manufacture uranium in three plants and plutonium in a fourth. The first three nuclear weapons were detonated in 1945,[1] the first in a test in the New Mexico desert and the second and third over the Japanese cities of Hiroshima and Nagasaki. The devastation from these detonations brought an end to the war and a realization of the overwhelming challenges that nuclear detonations or accidents present to medical providers. The single detonation in Hiroshima caused about 45,000 deaths and more than 90,000 casualties during the first 24 hours. The medical system could not handle the massive number of casualties because most medical treatment facilities and personnel were destroyed in the detonation.[2]

In subsequent years, the nuclear capability of the superpowers became overwhelming. As the years passed and the threat of a nuclear confrontation grew, efforts to restrain the use of nuclear weapons also grew. A nuclear nonproliferation agreement was signed[3] and included most, but not all, countries with nuclear capabilities. At the end of the Cold War, the United States and the Union of Soviet Socialist Republics initiated a disarmament program to decrease the stockpile of nuclear weapons. While nuclear weapons detonation from a theater or strategic nuclear confrontation is now much less likely to occur, the threat of a detonation from a terrorist group or an accident in one of the many industries that uses radioactive material is a growing concern.

BIOLOGICAL EFFECTS OF NUCLEAR WEAPONS

The radiation referred to in this chapter is ionizing radiation. Ionizing radiation can be divided into two categories, particulate and nonparticulate radiation. The most important types of particulate radiation are alpha, beta, and neutron; the nonparticulate types would be gamma rays and roentgen rays (Table 29-1).[4]

Alpha particles are helium atoms without their electrons. They are unable to penetrate the outer layer of the skin. Alpha radiation poses no external hazard but becomes hazardous if it enters wounds or body orifices. Internal contamination with alpha radiation is a significant long-term health hazard.

Beta particles are similar to electrons but come from the nucleus of the atom. They travel several meters in air and are capable of penetrating several centimeters into the skin. They represent a cutaneous radiation hazard and internal contamination hazard if deposited into deep-lying organs.

Neutrons are one of the uncharged particles in the nucleus of the atom. They are not directly ionizing but can penetrate the body and interact with body water, producing recoil protons that release energy by excitation and ionization. Neutrons are effectively shielded by hydrogenous material such as water and plastics.

Gamma rays are photons that travel great distances at the speed of light and can penetrate deeply into body tissues. The acute radiation syndrome is

TABLE 29-1

CHARACTERISTICS OF NUCLEAR RADIATIONS

Name	Emitted By	Range in Air	Tissue Penetration	Radiation Stopped By
Alpha	Unfissioned uranium and plutonium	5 cm	First layer of skin	Clothing, paper
Beta	Fission products	12 m	Several layers of skin	Clothing
Gamma	Fission products	100 m	Total body	Several feet of concrete, earth, water, or plastic
Neutron	Emitted only during fission	100 m	Total body	Several feet of concrete, earth, water, or plastic

Adapted from: Luckett LW, Vesper BE. Radiological considerations in medical operations. In: Walker RI, Cerveny TJ, eds. *Medical Consequences of Nuclear Warfare*. In: *Textbook of Military Medicine*. Washington, DC: Department of the Army, Office of the Surgeon General, Borden Institute; 1989: Table 10-1, p 229.

largely a result of significant exposure to gamma and roentgen rays. Shields for gamma rays are made of high-density concrete or lead.

The two major radioisotopes used in nuclear weapons are plutonium-239 and uranium-235. Plutonium emits alpha, beta, and gamma radiation. The type of radioactive exposure in a nonexplosive weapons accident is likely to be alpha radiation. The quantity present does not usually cause a significant external radiation hazard; contamination through intact skin results in little, if any, absorption. Internal exposure is another matter. The two major routes of internal exposure are through inhalation and wound contamination. The critical organs for systemic contamination are the bones and the lungs. Whole-body retention of internalized plutonium is detectable in body tissues for about 200 years, in the skeleton for 100 years, and in liver tissue for 40 years.

The primary physical effects associated with a nuclear detonation are blast, thermal radiation, and nuclear radiation. Each of these can cause injury and death. Burn injuries may occur alone or in combination with blast and radiation injuries. The production of blast and thermal injuries depends on the distance from ground zero of the casualty and the yield of the weapon. In a nuclear theater, the yield of a nuclear weapon is likely to be between 10 and 100 kilotons; the ranges for blast, thermal, and radiation injuries are likely to be similar.[4] The distance from ground zero for production of injuries that are fatal to half of those exposed is given in Table 29-2.

Blast Injuries

Blast injuries are either direct or indirect. Direct injuries result from high pressures of the blast wave (also called static overpressure), and indirect injuries result from missiles and displacement of the body by the blast winds (called dynamic overpressure). Following a nuclear weapon detonation, energy will be generated from the blast effects of the detonation and becomes the blast wave as it moves out from the blast center. A nuclear detonation also has a relatively long pressure pulse, which is more effective in causing blast injuries than a conventional weapon detonation. This blast wave produces

TABLE 29-2

THE DISTANCE (m) FROM DIFFERING SIZES OF NUCLEAR EXPLOSIONS THAT WILL PRODUCE INJURIES THAT KILL HALF THE PERSONS EXPOSED

	Weapon Yield (kilotons)			
Injuries	0.5	10	100	1,000
Static overpressure: 6 psi*	380	1,000	2,200	4,600
Thermal: 2 degree burns	580	2,100	5,500	14,500
Radiation: 500 cGy†	700	1,200	1,700	2,400

*pounds per square inch
†centigray
Source: Giambarresi L. Nuclear weapons: Medical effects and operational considerations. *7th MEDCOM Med Bull*. 1986;43(7):7–10.

injuries by exerting a crushing effect that engulfs the human body. The rate of increase of pressure is too rapid for the body to compensate, leading to large pressure differentials and resulting injuries. These static overpressure injuries include eardrum rupture, lacerations in alveoli and pulmonary vessels leading to pulmonary edema, superficial peritoneal hematomas, rupture of the liver and spleen, and intestinal perforations. Abdominal injuries resulting from static overpressure can occur in conjunction with thoracic injuries or by themselves. In the ileum, cecum, and colon there may be segmental perforations of the intestinal wall that result in peritonitis. This type of intestinal injury is more commonly seen in underwater blast injuries.

Indirect blast injuries from a nuclear detonation are similar to those of conventional weapons. The missile and displacement injuries from the blast wind of a nuclear detonation are products of lower overpressures than injuries from the blast wave. Injuries resulting from dynamic overpressures may be caused by the physical displacement of persons by winds and by impact injuries.[4] The relationship between static overpressure and dynamic overpressure wind velocities is shown in Exhibit 29-1.

EXHIBIT 29-1

WIND VELOCITIES CORRESPONDING TO PEAK OVERPRESSURES: THE RELATIONSHIP OF STATIC TO DYNAMIC OVERPRESSURES

Static Peak Overpressure (psi*)	Dynamic Overpressure Wind Velocity (mph†)
30	670
10	290
5	160
2	70

A nuclear weapon likely to be used during warfare would likely be in the 10 to 100 kiloton range and would produce 5 to 6 psi and roughly 160 to 200 mph winds. Distance from ground zero also has an effect, as does whether the detonation occurs in the air, underground, underwater, or on the surface. For a 1 megaton detonation, 6 psi would occur at about 4 km, lethal burns at about 14 km, and 5 Gy radiation levels at 2 km.

*pounds per square inch
†miles per hour
Source: Giambarresi L. Nuclear weapons: Medical effects and operational considerations. *7th MEDCOM Med Bull*. 1986;43(7):7–10.

Thermal Injuries

Of the wide spectrum of energies resulting from a detonation of a nuclear weapon, 35% is thermal energy. Thermal radiation causes direct burn injuries (ie, radiant energy absorbed by the skin) and indirect burn injuries (ie, ignition or heating of clothing by fires started by the radiation). The energies that cause these injuries are infrared radiation and visible light.Burns from infrared radiation are the most frequently seen injury. The burns are classified as flash burns or flame burns. Flash burns are caused by the direct effect of short pulses of thermal energy being absorbed by the skin, causing intense burns and charring of the skin. Because the skin is a poor heat conductor and the exposure is quick, though, flash burns are most often only superficial. Flame burns are caused by secondary fires (eg, burning buildings, tents, or clothing) ignited by radiation. Burn injuries add significantly to the patient load of the medical units. They occur alone or, what is more likely, in combination with blast and radiation injuries. The complications and logistical requirements for treating warfighters with burn injuries would place great demands on the battlefield medical units. It is predicted that at least two thirds of the radiation casualties will have combined injuries, that is, burns and other radiation exposure or wounds and radiation exposure. Burns produced the most significant synergistic effect on mortality in the combined injury model.[5]

Visible light energy will cause eye injuries, such as flash blindness and retinal burns. Flash blindness is caused by the initial flash of light produced by the nuclear detonation and results in transient blindness due to bleaching of the visual pigments in the retinal photoreceptors. The retina cannot receive the energy as rapidly as it is sent. This causes reversible blindness lasting from a fraction of a second to about 3 seconds and an after-image lasting several minutes if the detonation occurs during the day. If the detonation occurs at night, the flash blindness will be prolonged about 3-fold, with resulting inability to adapt to darkness for about 30 minutes. Retinal burns are caused by the thermal energy focused directly on the retina when the fireball is in the direct line of vision. Retinal burns usually cause permanent deficits in the visual field. Both types of thermal radiation (infrared and visible) travel at the speed of light so there is no chance of warning the affected population once a device has been detonated.

Radiation Injuries and Acute Radiation Syndrome

Neutrons and gamma rays are emitted in the fission process of a weapons detonation. They are referred to as "prompt" nuclear radiations because they are produced simultaneously with the nuclear explosion. Some neutrons may also undergo a scatter collision. Alpha and beta particles are quickly absorbed and only reach a few feet from the detonation. Radiation may produce injuries as a result of a single acute exposure to prompt neutrons and gamma rays from a nuclear detonation or from continual or intermittent exposure to residual radiation or fallout. The characteristic manifestations of radiation injury are dose and dose-rate related and called acute radiation syndrome (ARS).[6] ARS is a combination of relatively well-characterized clinical syndromes that occur in stages over a period of hours to weeks following exposure to radiation. The severity of symptoms depends on the dose, dose rate, dose distribution, duration of exposure, sensitivity of the cells to radiation, and cellular replication time. Cells that are more immature or undifferentiated are more sensitive to radiation. As cells mature or become more differentiated, they become less sensitive to radiation.

The clinical syndromes that make up ARS are hematopoietic syndrome, gastrointestinal syndrome, and central nervous system syndrome (sometimes called the cardiovascular/central nervous system syndrome or the neurovascular syndrome). Each of these syndromes follows a clinical course manifested in four stages that differ in intensity and duration based on the radiation dose. The first stage is the prodromal or initial stage, which occurs minutes to several days after exposure. Symptoms include acute incapacitation by nausea, vomiting, diarrhea, hyperthermia, erythema, hypotension, and central nervous system manifestations.[7] The latency stage, which follows the prodromal stage, is a period during which the patient is symptom-free and appears to have recovered from the radiation exposure. Next is the manifest illness stage, which is difficult to manage therapeutically because it is the period of maximum immunosuppression. Patient survival depends on the rapidity and aggressiveness of clinical therapy. The final stage is recovery, which depends on early treatment immediately after exposure and during the first several weeks following exposure coupled with individual sensitivities and preexisting conditions.[8]

The Hematopoietic Syndrome

The hematopoietic syndrome is seen after acute whole body exposure in the range of 1.5 to 8 gray (Gy, a measure of absorbed radiation dose equivalent to 100 rads). Doses less than 1 Gy of gamma radiation (in cases of exposure from a radiation accident, the radiation is likely to be primarily gamma radiation and some limited neutron radiation that cause ARS) usually produce few or no symptoms in humans. Higher doses may cause significant symptoms, and doses greater than 2.5 Gy may be life-threatening without therapeutic intervention. The prodromal stage, with its symptoms of transient nausea, vomiting, and diarrhea, occurs about 2 hours following exposure and may persist for several days. The latency stage may last for 2 to 3 weeks, at which time the manifest illness stage becomes evident. Significant symptoms occur at this time and may include fever, diarrhea, malaise, petechiae, epilation lymphopenia, and sepsis. The characteristic pathology of pancytopenia and death will result from hemorrhage and infection at doses of greater than 2.5 Gy without medical support. Half the humans exposed to a mid-lethal radiation dose of approximately 4.5 Gy will die if they do not receive medical intervention.[9] Though survival is still possible after acute whole-body exposures of around 8 Gy, exposures greater than 8 Gy usually result in 100% mortality, especially if there has been no medical intervention.[10]

The Gastrointestinal Syndrome

The gastrointestinal syndrome occurs after acute whole-body exposure to a wide range of doses (8 to 20 Gy). It is manifested earlier than the hematopoietic syndrome, usually occurring within 1 week of exposure. As early as 2 hours following exposure, the onset of prodromal symptoms will begin, and the latency stage can be as short as several days to about a week or even absent at the higher end of the dose range. Radiation interferes with the turnover of the mucosal cells lining the digestive tract.[11] The gastrointestinal mucosa lines the glandular structures in the submucosal space of the crypt epithelium. The columnar stem cells within the crypt regions are one of three less-differentiated cells. The intestinal stem cells are extremely radiosensitive, consequently leading to severe gastrointestinal symptoms from radiation damage. The damaged mucosa allows bacteria to enter the bloodstream. Patients present with vomiting, diarrhea, denudation of the small bowel mucosa, and sepsis. Early mortality is likely and is due to volume depletion and electrolyte imbalance with the characteristic symptoms of crampy abdominal pain and watery diarrhea that becomes bloody. This is followed by shock and death. While the gastrointestinal syndrome has a grave prognosis, those with lower-dose exposures may recover with medical management.

Central Nervous System Syndrome

The central nervous system syndrome is the least well characterized of the ARS syndromes. It is believed that doses of above 10 Gy may result in direct toxic damage to the nervous system,[12] but this syndrome occurs after doses of radiation of 20 to 30 Gy or greater.[9] Prodromal symptoms usually occur within minutes of exposure and persist for about 2 days. Laboratory animal data are relied on for this syndrome as there is little human information available on exposures in this range. It is known that death occurs relatively quickly following exposure. The presenting symptoms are lethargy, hypotension, hyperexcitability, disorientation, confusion, ataxia, respiratory distress, and convulsive seizures; these can quickly develop into coma and death. Pathological changes are evident and include microvascular damage (vasculitis) and increased intracranial pressure, cerebral edema, and cerebral anoxia. Radiation doses in this range are universally fatal even with medical intervention.

Combined Injury

Combined injury is the association of radiation injury with thermal burns, traumatic or other mechanical wounds, or both. The mortality rate for combined injuries increases significantly in the absence of medical care. An otherwise benign traumatic or burn injury may become lethal when combined with radiation exposure in excess of 2 Gy. Radiation and conventional injury seem to act in a synergistic manner and result in increased mortality. The biological effect of combined injuries will significantly increase the casualty's burn injuries and affect his or her ability to recover from a nuclear detonation.[13,14]

CASUALTY MANAGEMENT

Traditionally, military medical readiness for nuclear warfare has been focused on the management of large numbers of casualties resulting from a massive nuclear exchange between major powers. Modeling of nuclear scenarios for today's medical preparedness requires readiness training and understanding of medical operations in a nuclear environment or a radioactively contaminated environment.[15–17] With increasing use of nuclear materials, there is an increased probability of accidental radiation exposure or contamination of individuals working with or around such nuclear material. Examples include the release of radiation in Chernobyl, Ukraine (1986)[18]; Brazil (1987)[19]; and Tokaimura, Japan (1999).[20] A person's external or internal exposure to radiation or radioactive material does not, however, constitute a medical emergency. Contamination, whether internal or external, must be minimized as soon as possible to prevent further exposure to the individual and decrease the possibility of spreading contamination to the general public.

Triage

Triage is a mechanism of rapid evaluation of casualties based on their clinical condition and the prioritization of their treatment based on that evaluation. It is a process of sorting at the accident or detonation site. Triage priority should be given to victims with a good likelihood of recovery. The two keys to effectiveness and efficiency in the triage system are speed of assessing and categorizing patients and coordination of resources. Patient flow and response to care are integral parts of triage. They must be continually reassessed and reevaluated. The designated triage officer must have a well-trained response team. Good clinical judgment, intuitive clinical acumen, ability to handle stress, and awareness of available resources are but a few of the required characteristics of a good triage officer.

The health and safety of the general public in a nuclear exposure, whether from nuclear weapons detonation or power plant accidents, is a critical concern for the first emergency management responders to arrive at the accident scene (the response team) and depends on the exposure rate, the quantity of radioactive material present, and the public's perception of radiation exposure.[21] A nuclear weapons accident may result in immediate nonradiological threat from toxic or explosive hazards to the general public. The radiological contamination can also create a long-term concern of risk to the public's health. In a weapons accident, it is likely to be alpha particles that are the primary radiological hazard, not beta or gamma radiation. Dose effects from given exposures and dose rates of external and internal contamination provide data for the prediction of clinical response in the contaminated patient.

Contamination: External and Internal

Fallout causes an external hazard from gamma and high-energy beta emitters. Significant reduction in this exposure can be achieved through timely decontamination or prevention of external contamination. To keep the exposure to a minimum, the principles of time, distance, and shielding should be applied. Shielding is simply using protective clothing or placing dense material between the person and the radiation source. Surgical attire such as gowns, caps, shoe covers, and gloves will provide protection from beta radiation. Minimizing the time spent in the contaminated environment will reduce the radiation dose, and maintaining a significant distance from the radiation source can reduce the exposure. From ground zero or the point source of radiation, the level of radiation falls off by the square of the distance away from the source. This is similar to the seven-ten rule, which indicates that at any given time after exposure the radiation reading seven times later will decrease by a factor of ten from the original reading[22] (Table 29-3).

TABLE 29-3

SEVEN-TEN RULE FOR RESIDUAL RADIATION DECAY

Time Passed (h)	Fraction of Original Reading Remaining
1	1.0
7	0.1
49	0.01
343	0.001

Source: Vesper BE. External decontamination. *7th MEDCOM Med Bull*. 1986;43(7):30–31.

Most radiation does damage only after entering the body. Cursory decontamination, such as brushing off radioactive fallout dust or washing exposed skin, will reduce the radioactive exposure and minimize the risk that radioactive material will be internalized. Radiation injuries from internal contamination occur through various routes, such as inhalation, ingestion, and absorption from contamination on the skin or in wounds. The number of radionuclides with potential for internal contamination are many, but they are rarely encountered or represent only minor hazards to humans. The human body rarely incorporates enough radioactivity to cause ARS or to become acutely life-threatening. The late consequences of internal contamination, however, pose a greater potential risk. Whenever an unusually large dose of radionuclide is internalized, it is important to treat the individual as if he or she had ARS while also attempting to decorporate, mobilize, or block the radionuclide. The hematopoietic system, gastrointestinal system, and lungs should be given special attention. Radioactive isotopes of an element can behave differently when internalized into a biological system. Some isotopes preferentially taken up via gastrointestinal absorption are cesium (^{137}Cs), iodine (^{131}I), phosphorus (^{32}P), strontium (^{90}Sr), and tritium (^{3}H).[23]

Some actinides (eg, plutonium, americium, uranium, curium) and other radionuclides (eg, polonium, radium, iodine) of medical significance enter the body primarily via inhalation. Inhalation of radionuclides into the bronchial tree and alveoli and transport across the alveoli into the bloodstream depend on the particle size and solubility. Of the radioactive isotopes inhaled, about 25% are deposited in the nasal passage and upper bronchial tree; cilia move them to the nasopharynx where they are swallowed and enter the gastrointestinal tract. The remaining particles are deposited in the airways, trachea, and pulmonary lymph nodes and deep in the lungs. Highly insoluble oxide forms of compounds are retained in the lungs for a longer period of time before being translocated to the tracheobronchial and pulmonary nodes and finally to the liver years after exposure.[24]

Treatment

For treatment purposes, patients with radiation injury are classified according to the severity of radiation exposure. The categories are mild, moderate, severe, and lethal. Treatment should be based on the injury, not the radiation dose estimated from a film badge or other measuring device (Figure 29-1). The most reliable guides are changes in levels of blood cells and cytogenetics resulting from bone marrow injury. Hematopoietic growth factors, such as granulocyte colony-stimulating factor (G-CSF), are potent stimulators of hematopoiesis and when administered early following radiation exposure may induce effective granulocytosis and prevent the consequences of severe neutropenia. Marrow transplantation may also be indicated in some cases.[25]

Management of those with internal contamination depends on the ability of the provider to decrease internal absorption and deposition or to increase excretion and elimination of the absorbed radionuclide. Early care is the most effective.[26] Lung contamination may quickly spread to the blood and target organs if the material is soluble and smaller than 5 μm. Larger soluble particles will likely remain in the lung, resulting in direct damage to lung tissue. Treatment for soluble material is dilutional (eg, blocking, chelating, mobilizing) to enhance excretion. Lung lavage may be useful for insoluble radionuclides but should only be used as a last resort because of associated complications of the procedure and the need for an experienced provider to perform it.

Infections

Infectious complications are another consequence of radiation exposure. For those exposed to sublethal levels of radiation, infections can be prevented with the use of immunomodulators to enhance nonspecific resistance to infection. Initial medical care of patients with moderate (2-5 Gy) and severe (5-10 Gy) radiation doses should include early measures to reduce pathogen acquisition, such as emphasis on food with low microbial content, frequent hand washings or the wearing of gloves, and air filtration. Prophylactic selective gut decontamination with oral antibiotics is recommended. Antiemetic agents, such as the H2 blockers, are required to control nausea and vomiting.

The management of existing or suspected infection (eg, neutropenia, fever) in irradiated persons is similar to care provided to other immunocompromised, febrile, neutropenic patients. First, a regimen of

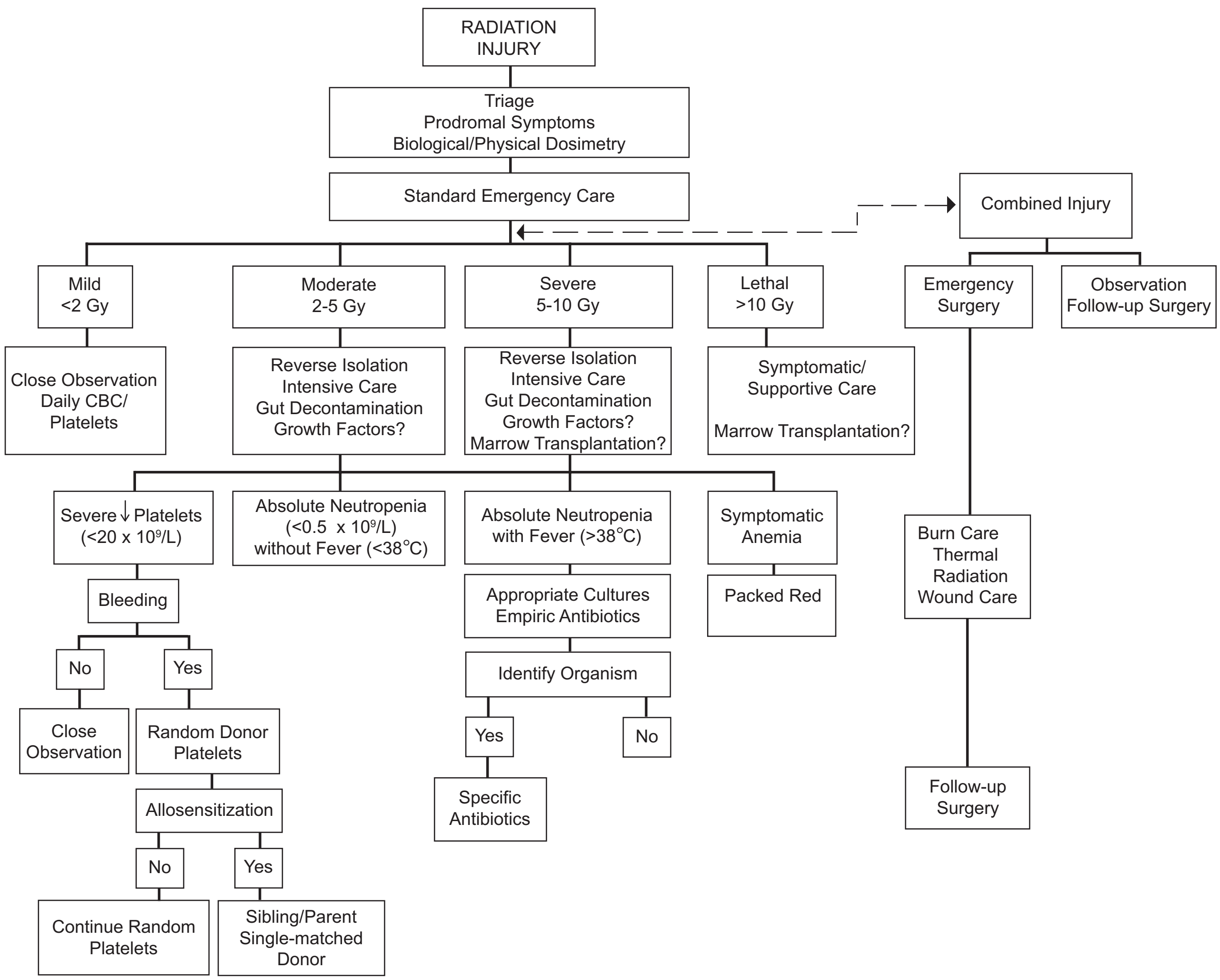

Fig. 29-1. Treatment Schema for Radiation Injury
Reproduced with permission from Browne D, Weiss JF, MacVittie TJ, Pillar MV, eds. *Treatment of Radiation Injuries*. New York: Plenum Press; 1990.

empiric antibiotics should be selected based on the pattern of bacterial susceptibility, nosocomial infections in the care facility, and the degree of neutropenia. Combination antibiotic regimens (eg, broad spectrum beta-lactam penicillin or cephalosporin plus aminoglycoside with or without vancomycin) are recommended for initial therapy for patients with profound neutropenia. Monotherapy, using drugs such as imipenem or ceftazidime, is appropriate for patients with less intense neutropenia. Antifungal drugs such as amphotericin B or fluconazole should be added, if indicated, for patients who remain febrile for 7 days or more while on or after 7 days of antibiotic therapy. If the fever and neutropenia persist for more than 48 hours after the start of antibiotic and antifungal therapy, viral titers should be obtained and antiviral therapy (eg, acyclovir) added. In cases where there is resistant gram-positive infection, vancomycin should be added. Cultures may be useful for monitoring acquisition of resistant bacteria and the emergence of fungal infections.[25]

Combined Injuries

Because the prognosis for combined injuries is worse than for either traumatic injury or radiation injury alone, it is important that comprehensive medical care is initiated to reduce mortality, especially if a total-body radiation exposure of sublethal or medium-lethal levels is combined with various types of conventional insults (eg, trauma, burns). Emergency and definitive care for combined injuries include early surgical interventions. Management of burns and soft tissue injuries is more difficult in combined injured casualties due to loss of skin and muscle, damage to vasculature, and necrotic tissue. It is recommended that surgical management for combined injury wounds and thermal burns be initiated as soon as possible but at least within 36 to 48 hours of radiation exposure. Elective surgical procedures should not be done until the patient is showing signs of recovery from the hematopoietic injury or is responding to cytokine therapy.

The Skin

Skin damage from radiation exposure occurs in varying degrees and is related to radiation quality and absorption of the radiation dose. Radiation burns may require repeated therapy and prolonged rehabilitation. Initial management is conservative; analgesic support, antibiotics, and surgical intervention may become necessary as the tissue becomes necrotic, painful, and infected. Good clinical judgment and management expertise in local radiation injury is necessary to prevent unnecessary suffering by the patient. Magnetic resonance imaging, radioactive isotope scanning, and thermography can help assess the extent of tissue damage, sufficiency of local microcirculation, and viability of the remaining tissue.[27]

PROTECTION FROM RADIATION

Every effort must be made to minimize radiation exposure and contamination in a radiation environment. Time, distance, shielding, and contamination control are the basic factors to consider in controlling or minimizing radiation exposure. After a nuclear detonation, fallout can be expected to contaminate equipment and personnel. The radiation dose received is directly proportional to the time of exposure. The shorter exposure, the less radiation received, so minimizing the time spent in the contaminated area will reduce radiation exposure. The radiation dose can be estimated by multiplying the dose rate at a specified point by the time the person remains at that location. To minimize exposure, tasks that must be performed in a contaminated area must be planned in advance and a stay-time established so as not to exceed a certain dose of radiation. Exposed personnel should decontaminate as quickly as possible to lower their total radiation exposure. Time can be used to allow the radiation to decay naturally. The seven-ten rule is a good general rule (see Table 29-3).

Respiratory protection and contamination control during the weapons recovery phase (the period when the weapon is being located and it is determined if the nuclear component has detonated) is a priority task for a nuclear accident response team. The first responders, such as the firefighters and the explosive ordnance personnel, will not usually have enough radiation survey equipment to assess the situation properly because of the urgent need to reduce the serious hazards of fire and potential explosion. These personnel rely on well-rehearsed standard operating procedures and well-designed protective equipment. Following the initial operations, the response force will establish a contamination control station near but upwind from the accident location. At the accident site, there may be extremely high levels of contamination on equipment and debris and resuspension of fine particulate, which will make respiratory protection necessary. There may also be physical and toxic hazards.

Respiratory protection criteria are based on the conditions at the accident site. Less respiratory protection may be needed in locations where the contamination is no longer airborne than in areas with high resuspension rates or during periods of high winds. Workers' exposure to airborne particles should be limited, but this must be done within the imperatives of the operations being performed. To quantify the contamination level, a target protective action guide (PAG) is established. If the averaged air concentration of radioactive particles is above this PAG, the situation should be evaluated and respiratory protection considered. For most work, the PAG is an averaged air concentration of 1.5 Bq/m^2. This approximates an exposure of 2×10^{-4} Sv for each hour of exposure. For the initial phase, 250 hours of work can be performed before the annual dose limit of 0.05 Sv is attained.[28] If the air concentration is well documented, a person can be allowed to enter an area of higher activity for a shorter period of time, as long as the whole-body exposure is well documented. Decontamination is necessary for all persons and equipment after leaving the contaminated area, and qualified technicians must monitor the level of radioactivity before granting access to noncontaminated areas.

The isolation gowns or surgical scrub garments used when universal precautions are being followed for communicable disease control are suitable for protection from external radiation contamination. There is also specially made anti-contamination protective clothing.

SUMMARY

It is an increasing probability that military forces will be faced with situations of radiation exposure in operational environments other than war. This risk can occur as a result of weapons dispersal, damaged nuclear reactors, medical and research facilities' sources, industrial waste dumps, depleted uranium munitions, and terrorist attacks. With the increased nuclear capabilities in the world today there is an ever-present likelihood of radiation accidents occurring. Health care providers must be prepared to handle the medical aftermath of an accidental nuclear exposure. While much of the medical management will be based on clinical judgement and astute evaluation, it is necessary to have a plan of medical management available to deal with the contingency of an unforeseen nuclear event. The casualty must be assessed for the presence of a combined injury, the type and level of radiation exposure must be calculated, and the treatment and decontamination begun as rapidly as safely possible. In a massive casualty situation the success of the medical operations will depend on the adequacy of the planning, training, and pre-positioning.

Based on past massive casualty situations, a significant disparity may exist between the available medical resources and the casualties needing therapeutic management. The establishment of policies and doctrines along with a rigorous plan for training and implementation must be instituted before a contingency looms. Past experiences and wartime consequences have shown that it is imperative to be prepared for any nuclear contingency and include mechanisms to handle the psychological stresses that follow radiation exposure and its potential late effects.

A better understanding of the effects of radiation and trauma will result in improved management of radiation casualties and a decrease in the logistical drain on limited medical resources. A multidisciplinary approach is needed to manage life-threatening outcomes resulting from accidental exposure to radiation.

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