MEDICAL MANAGEMENT
OF RADIOLOGICAL CASUALTIES

Online Third Edition **June 2010**

Military Medical Operations
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The Medical Management of Radiological Casualties Online Third Edition, June 2010, generally reflects the content of the QuickSeries-produced November 2009 hard copy field guide by the same title. However, minor corrections are included in the Online Third Edition on pages 5, 6, 12, 13, 19, 24, and 33 and, while some images were not available for inclusion, all critical images are present. The handbook content was prepared by Ronald E. Goans, PhD, MD, and edited by AFRRI Military Medical Operations staff.

The Online Third Edition is available from the AFRRI Web site at http://www.afrri.usuhs.mil/outreach/infoprod.htm#guide. It is cleared for public release with distribution unlimited.

The QuickSeries November 2009 pocket-size, laminated field guide may be requested by members of the U.S. Department of Defense as follows: e-mail MEIR@afrri.usuhs.mil or telephone 301–295–0316 or write Military Medical Operations, AFRRI, 8901 Wisconsin Avenue, Bethesda, MD 20889–5603. The guide also is available at http://www.quickseries.com.

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"We do not have the excess medical capacity in our U.S. healthcare system to respond to a nuclear weapon. This handbook will help those with minimal knowledge of what ionizing radiation does to the human body."

Patricia K. Lillis-Hearne, COL, MC, USA
Director, Armed Forces Radiobiology Research Institute
July 20, 2006–April 16, 2010

Additional Radiation Response Resources

Radiation Emergency Assistance Center/Training Site (REAC/TS)
http://orise.orau.gov/reacts/

The REAC/TS mission for the U.S. Department of Energy (DOE) is twofold: Provide 24/7 availability to deploy and provide emergency medical services at incidents involving radiation anywhere in the world and to provide advice and consultation on radiation emergency medicine from its Oak Ridge, TN, headquarters.

USG DHHS Radiation Event Medical Management (REMM)
http://www.remm.nlm.gov/

Part of the U.S. Department of Health & Human Services, REMM provides guidance on radiation-event diagnosis and treatment for healthcare providers.

Centers for Disease Control and Prevention (CDC), Emergency Preparedness and Response
http://emergency.cdc.gov/

This government website is intended to increase the nation's ability to prepare for and respond to public health emergencies, including radiological events.

Radiation Injury Treatment Network (RITN)
http://www.ritn.net/

RITN provides comprehensive evaluation and treatment for victims of radiation exposure or other marrow toxic injuries, develops treatment guidelines, educates healthcare professionals, works to expand the network, and coordinates situation response.

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Emergency Response

This handbook addresses medical management of casualties in the first 72 hours of a radiation event. The most important consideration in the medical evaluation of a radiation event is the relative magnitude of the situation and the resources needed to address the emergency. In many cases, order of magnitude estimates of the scale of the event will be sufficient for emergency response.

- Small-scale events are those occurring in laboratories, hospitals, nuclear power plants, etc., involving small amounts of radionuclides with the potential exposure and/or contamination of one or a few individuals.
- Large-scale events are those involving relatively large quantities of radionuclides and the potential exposure or contamination of large numbers of people, e.g., terrorist attacks with radiological weapons, nuclear weapons detonation, and large-scale nuclear power plant disasters.

High-level external ionizing radiation poses the greatest danger to living organisms. Low levels of internal or external contamination generally pose very low risk. A site known to be radiologically contaminated should be surveyed before entering and responders should be advised to limit their time in high dose-rate areas. There is generally no hazard associated with handling a radiologically contaminated casualty. See the topic Decontamination Techniques.

U.S. military planning. The U.S. military has established a system for mission-specific risk-based dose limits that includes life-saving activities. In current doctrine, U.S. military personnel become restricted from engaging in operational radiological/nuclear missions once they have exceeded a 125-cGy dose accumulation. Military commanders set their Operational Exposure Guidance (OEG; i.e., dose limits to U.S. troops) in nuclear war. For operations other than war, military commanders generally limit OEG levels to 75-cGy. For guidance see JP 3-11, Operations in Chemical, Biological, Radiological, and Nuclear (CBRN) Environments, 26 August 2008.

Triage

Triage should be conducted based on traditional surgical and medical considerations. Radiation injuries in the absence of trauma are covered in the topics Acute Radiation Syndrome, Medical Management of Skin Injury, and Medical Management of Internally Deposited Radionuclides. Medical aspects of weapons effects are described in Other Injuries from Nuclear Weapons.

Radiation interacts synergistically with trauma. Patients with medical or traumatic injury who also have whole-body or significant partial-body irradiation (see the topic Combined Injury) have a substantially worse prognosis and will require a higher triage priority, as shown in Table 1.

Table 1. Triage Categories. ▲

Physical injury without irradiation	Expected changes in triage categories after whole-body irradiation		
	< 2 Gy Vomit > 4 h	2–6 Gy Vomit 1–4 h	> 6 Gy Vomit < 1 h early erythema
Uninjured	Ambulatory monitoring	Ambulatory monitoring, Administer cytokines and delay hospitalization	
Minimal	Minimal	Delayed	
Delayed	Delayed	Variable	
Immediate	Immediate		
Expectant			Expectant

For externally irradiated patients without trauma, patients receiving a high dose can be distinguished from those with a dose < 1 Gy using two criteria: the neutrophil/lymphocyte (N/L) ratio and whether emesis has occurred. A triage score T is assigned as follows.

$$T = N/L + E, \text{ where } E = 0 \text{ if no emesis; } E = 2 \text{ if emesis.}$$

In a normal, healthy human population, the N/L ratio from a complete blood count (CBC) with differential has been found to be ~ 2.1. For time > 4 h post-event, T is significantly elevated for doses > 1 Gy. One study has shown this scoring technique to have a sensitivity of 89% and a specificity of 93% to separate those with doses < 1 Gy from those with higher doses (N = 226 controls, N = 36 radiation cases; median dose, 3 Gy; REAC/TS Radiation Accident Registry). A cut-point of 3.7 has been chosen to maximize sensitivity and specificity. If T is > 3.7, the patient should be referred for further evaluation.

Major Medical Issues

- Victims of radiological terrorism or wartime events require prompt diagnosis and treatment of medical and surgical conditions as well as conditions related to radiation exposure. Medical and nursing personnel have never received a significant radiation dose when providing patient care to radiation casualties. The only exception might occur if highly radioactive shrapnel is embedded in the patient. This has never happened but should be considered in medical planning.
- Radiation dose can be estimated early post-event from the medical history, serial blood counts, and the time to emesis (TE). Dose may be subsequently confirmed with chromosome-aberration bioassay, the current gold standard.

- Data from an initial baseline CBC with differential, if possible, and repeated q 6 h can be effectively analyzed using the Armed Forces Radiobiology Research Institute (AFRRI) Biodosimetry Assessment Tool (BAT). BAT produces a harmonized estimate of dose using all input parameters as well as expert opinion.
- Lymphocyte depletion follows dose-dependent, first-order kinetics after high-level gamma and criticality incidents, while the N/L ratio increases over the first few days post-exposure. Both are sensitive indicators of radiation dose.
- For TE < 2 h, the effective whole-body dose is at least 3 Gy. For TE < 1 h, the whole-body dose most probably exceeds 4–6 Gy. Conversely, if the patient has not vomited within 8–10 h post-event, the whole-body dose is likely < 1 Gy.
- Medical management of patients with acute, moderate-to-severe radiation exposure (effective whole-body dose > 3 Gy) should emphasize the rapid administration of colony-stimulating factors (CSFs) to enhance hematopoietic recovery. All of these compounds decrease the duration of radiation-induced neutropenia and stimulate neutrophil recovery, albeit with some variability.
- Currently, the only hematopoietic CSFs with Food and Drug Administration (FDA) marketing approval for management of treatment-associated neutropenia are recombinant forms of granulocyte colony-stimulating factor (G-CSF, Neupogen®), granulocyte-macrophage colony-stimulating factor (GM-CSF, Leukine®), and the pegylated form of G-CSF (Neulasta®). Recommended dosages are given in the topic Acute Radiation Syndrome.
- For patients developing febrile radiation-induced neutropenia, adherence to the current Infectious Disease Society of America guidelines for high-risk neutropenia is recommended.

Required Initial Labs (Field or Emergency Department; ED)

- CBC with differential and repeat q 6 h: To evaluate lymphocyte kinetics and to calculate the N/L ratio.
- Serum amylase (baseline and q d after 24 hours). A dose-dependent increase in amylase is expected after 24 hours.

Important Labs to Obtain (If Feasible)

- Blood FLT-3 ligand levels: Marker for hematopoietic damage.
- Blood citrulline: Decreasing citrulline indicates GI damage.

- Cytogenetic studies with overdispersion index to evaluate for partial-body exposure.
- Interleukin-6 (IL-6): Marker increased at higher radiation dose.
- Quantitative G-CSF: Marker increased at higher radiation dose.
- C-reactive protein (CRP): Increases with dose; shows promise to discriminate between minimally and heavily exposed patients.

Recommended Anti-Emetic Dosages

The following dosages of selective 5-HT3 receptor antagonists are recommended for radiation-induced emesis.

- **Ondansetron (Zofran®, Zofran ODT®):** Initial, 0.15 mg/kg IV. A continuous IV dose option consists of 8 mg followed by 1 mg/h for the next 24 hours. Oral dose, 8 mg q 8 h as needed.
- **Granisetron (Kytril®):** Oral dosage (tablets), usually 1 mg initially and repeated in 12 hours after the first dose. Alternatively, 2 mg may be taken as one dose. IV dose is based on body weight; it is typically 10 mcg/kg (4.5 mcg/lb) of body weight.

▲

Introduction

Radiologically contaminated patients generally pose no danger to healthcare personnel. Hence, medical professionals must be prepared to provide prompt treatment of conventional trauma complicated by ionizing radiation or radioactive contamination. Two principles are of paramount importance in the medical management of the irradiated patient: early estimation of the magnitude of the radiation event and identification of the radioisotope(s) in question. These principles strongly influence subsequent treatment decisions.

Radiation Threat Scenarios

The National Council on Radiation Protection Report No. 138 (2001) defines three types of devices by which military personnel could be exposed to radiation. These affect the way people are exposed to radiation effects and the biological effects to be expected.

- **Radiation exposure device (RED):** radioactive material, in a sealed source or within a container, intended to expose people in the vicinity of the device to a high-level external dose. Some materials used in military equipment and supplies contain radioactive components that, if improperly handled, could function as an RED. Industrial radiography sources constitute the most prevalent REDs in the civilian sector.
- **Radiological dispersion device (RDD):** any device that causes intentional dissemination of radioactive material without a nuclear detonation. An RDD can cause organ dose through inhalation of radioactive material in a dispersal plume or ingestion of materials in the food chain. An RDD would cause conventional casualties to become contaminated with radionuclides and the contaminated area would complicate medical evacuation.
- **Improvised nuclear device (IND):** device designed to produce a nuclear explosion, at full or partial yield. An IND is physically the same thing as a nuclear weapon: blast, thermal, and radiation are the forms of energy and also the cause of injury. An IND exposes people to high-level external dose, trauma, inhalation of radioactive materials, particulate contamination, and ingestion of radioactive materials in the food chain.

Significant amounts of radioactive material may be deposited on surfaces after the use of any nuclear weapon or RDD, the destruction of some types of nuclear reactors, a nuclear accident, or improper nuclear waste disposal. Operations in contaminated areas could result in military personnel receiving sufficient radiation dose or particulate contamination to warrant medical evaluation and remediation.

In addition to the above, military personnel can be exposed to radiation from accidents involving storage or transportation of nuclear materials, industrial

sources, or unsecured high-level sources in a hostile environment. For example, military support was an integral aspect of Project Sapphire, a covert, combined Department of Defense (DOD), Department of Energy (DOE), and Department of State (DOS) operation to recover highly enriched weapon-grade uranium from Kazakhstan.

Personnel Protection

After a ground burst of a nuclear weapon or RDD, the area of detonation would be heavily contaminated and require demarcation until sufficient radionuclide decay occurred. Areas of contamination could also result from industrial or medical source destruction, radioactive waste disposal, or use of an RDD.

External contamination by radionuclides will occur when a soldier traverses a contaminated area without appropriate barrier clothing. If the individual is wounded while in the contaminated area, he will possibly become an internally contaminated patient.

Standard issue chemical protective masks afford excellent protection from inhalation and ingestion of radioactive material. Radon and tritium gas will pass through the filters, but short exposures are not medically significant.

Commercial anti-contamination suits (Tyvek® Anti-C Suits) are far from ideal in a tactical military situation and offer little advantage over standard mission-oriented protective posture (MOPP)-4. However Tyvek® suits are preferred if heat stress is a concern and the contamination threat is only ionizing radiation. Chemical-protective overgarments provide excellent contamination protection as well as protection from chemical-biological agents.

Standard hospital barrier clothing as used in Universal Precautions is adequate for emergency treatment of limited numbers of radiologically contaminated casualties. Medical personnel should be decontaminated following emergency treatment and decontamination of contaminated patients, i.e., patients affected by an RDD or IND (but not an RED).

Radiation Effects

Ionizing radiation deposits energy into human tissue, thereby disrupting the normal anatomic structure and the physiological actions of various organs. The pathological effects of radiation are directly related to dose. Dose is defined as the amount of energy deposited by radiation per unit mass of tissue. It is a total body injury with different tissues expressing damage over time.

Means of Exposure

A soldier may receive radiation dose from an external device (RED), by ingesting or inhaling radiological particulates (RDD), or through loose radioactive material

deposited on the skin or equipment. It is usually high-level external radiation from a weapon or RED that is lethal in an acute setting. Ingestion or inhalation of radioactive material may cause internal dose to the whole-body or to a specific organ over a period of time, but historically dose received in this manner normally has not been lethal.

Types of Radiation

Four types of radiation are important in military medicine.

- **Alpha particles:** charged particles emitted from heavy nuclei such as U, Pu, or Am. Alpha particles cannot travel far and are fully stopped by the dead layer of the skin or by a uniform. They are therefore a negligible external hazard but can be important in an inhalation incident. Absorption via the GI tract is usually of limited importance, but absorption from wounds can be medically significant.
- **Beta particles:** electrons found in weapons fallout and emitted from isotopes such as tritium and strontium. Beta particles can travel a short distance in tissue. Large quantities deposited on the skin can damage the basal layer and cause radiation burns. Beta emitters also are important if inhaled or ingested.
- **Gamma rays:** massless photons emitted during a nuclear detonation, by fallout, and in many instances of nuclear decay. They are highly energetic and pass through matter easily. Because of its high penetrability, gamma radiation can result in whole-body exposure and damage to deep organs. Gamma-emitting nuclides are medically important in external exposure and in inhalation and ingestion.
- **Neutrons:** uncharged particles important because they are emitted from the fission process in a nuclear detonation. Neutrons can cause 2–20 times as much damage to tissue as gamma rays.

Units

The unit of radioactivity is the curie (Ci) defined as 3.7×10^{10} becquerel (Bq) where 1 Bq is defined as one disintegration per second. The unit of absorbed dose (rad) is a measure of the energy deposited in tissue by ionizing radiation. The International System unit for absorbed dose is the gray (Gy).

1 Gy = 100 rad; 10 milligray (mGy) = 1 rad.

Dose rate is the dose per unit of time. Free-in-air dose refers to the radiation dose measured in air at a certain point. Free-in-air dose is easy to measure with current military field instruments, and more meaningful doses, such as midline tissue dose or dose to the blood-forming organs, may be estimated by this approximation. Military tactical dosimeters also measure free-in-air doses.

Differences among radiation types are adjusted by use of a quality factor (QF). The dose in rads times the QF yields the rem, or radiation equivalent, man. The international unit for this radiation equivalency is the sievert (Sv). The QF for x-ray or gamma radiation is one, so for pure gamma radiation,

100 rad = 100 cGy = 1000 mGy = 1 Gy ~ 1 Sv = 100 rem = 1000 mSv.

For acute medical effects, it is widely considered that the most appropriate unit to use is the rad or Gy. The rem or Sv is useful for long-term effects such as the risk of radiation-induced cancer. Equivalent units are listed in Appendix Table 9.

Military or civilian instruments such as the Geiger-Mueller (G-M) counter or ion chamber often measure the roentgen (R) or a submultiple such as mR. The R is a unit of ionization. For military purposes and for essentially all civilian situations, 1 R ~ 1 rad ~ 1 rem. So, even though the units are different, they are often used interchangeably in emergency events and in hospitals.

Gamma Ray Exposure Rate

The gamma constant for an isotope is the gamma ray exposure rate in R per hour (R/h), or its international equivalent, at 1 m distance per curie of activity. Three common isotopes are thought to be items of interest to terrorist organizations, Ir-192, Cs-137 and Co-60.

One can use the following approximate gamma constants (point source; within 3% of exact values) that are easy to remember:

Co-60: 4/3 R/h at 1 m distance per Ci

Cs-137: 1/3 R/h at 1 m distance per Ci

Ir-192: 1/2 R/h at 1 m distance per Ci

Clinical Example: Determining Dose

Event. An individual goes into an abandoned apartment where a new 100-Ci Ir-192 source is hidden in the wall. The source, initially intended for industrial radiography, was diverted to a war zone. The patient goes within 1 m of the source before a colleague warns him of a suspicious metallic cylinder. He estimates being in the vicinity of the source for 15 minutes. What is his estimated whole-body dose?

Solution. An approximate dose from a small source is the gamma constant, multiplied by the activity of the source, times the amount of time spent near the source, divided by the square of the person's distance from the source in meters. The gamma constant for Ir-192 is ~ ½ R/h at 1 m per Ci.

Dose = ½ R/h × 100 Ci × ¼ h ~ 12.5 rad.

In this case, there would be no significant medical consequence to the patient. Reassurance to the patient would be in order regarding medical issues. Although this is a rough approximation, it is adequate given the usual uncertainty in the individual's distance from the source and the time spent near it. The dose rate for a point source decreases as the square of the distance, so the dose would be substantially smaller at greater distances from the source.

At 1 m dose ~ 12.5 rad

At 2 m dose ~ 12.5 rad/22 = 12.5/4 rad ~ 3 rad

At 3 m dose ~ 12.5 rad/32 = 12.5/9 rad ~ 1.3 rad etc.

It is therefore important to minimize time near a source and maximize distance from it. This case is based on a real event in the civilian sector.

Acute Radiation Syndrome

ARS results from high-level external exposure to ionizing radiation, either of the whole body or a significant portion (> 60%) of it. For this purpose, “high-level” means dose greater than 1 Gy delivered at a relatively high dose rate. Radiation dose can be estimated early post-event using rapid-sort, automated biodosimetry and multi-parameter methods including the clinical history, TE, lymphocyte depletion kinetics, and multiple biochemical markers. Victims of radiation events require prompt diagnosis and treatment of medical and surgical conditions as well as conditions related to radiation exposure.

Etiology

Some radiation damage to cells occurs within microseconds of exposure. Radiation damage results from the inherent sensitivity of certain cell types to radiation, with the most replicative cells being the most sensitive to acute effects. This damage gives rise to a constellation of clinical syndromes. Compare the normal bone marrow (Figure 1) to the pyknotic stem cells damaged by radiation (dose > 2 Gy) in Figure 2.

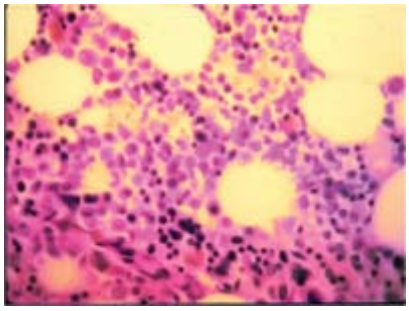


Figure 1. Normal bone marrow. ▲

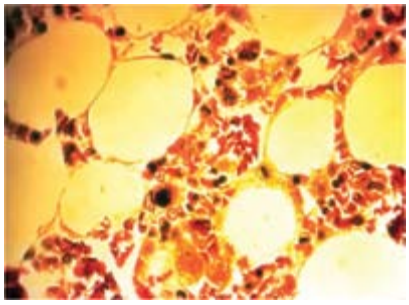


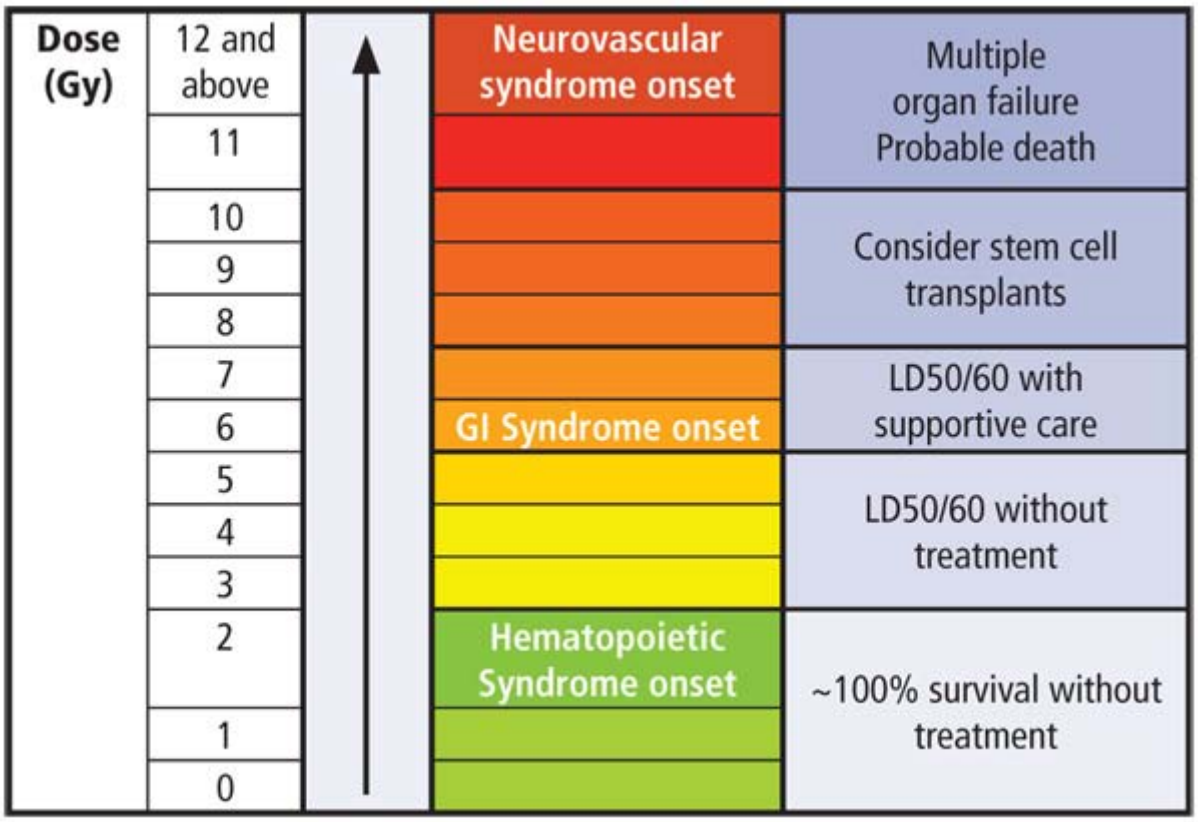
Figure 2. Stem cells damaged by radiation. ▲

Phases and Syndromes

ARS is an acute illness that follows a roughly predictable course over a period ranging from a few hours to many weeks. Like a viral illness, it exhibits prodromal symptoms, a latent period, a period of well-defined illness, and a phase of recovery or death. ARS is characterized by the development of groups of signs and symptoms that manifest the reactions of various body systems to irradiation. Phases and likely outcome are shown in Table 2.

Prodromal signs and symptoms of high-level radiation exposure include anorexia, nausea and vomiting, diarrhea, mild fever, conjunctivitis if the radiation dose is near the eyes, and possible transient skin erythema.

Table 2. Radiation Effects. ▲



The ARS includes a subclinical phase (< 1 Gy) and three sub-syndromes resulting from whole-body irradiation or irradiation to a significant fraction of the body.

- Hematopoietic syndrome (~ 1–8 Gy)
- GI syndrome (~ 5–6 Gy to 20 Gy)
- Neurovascular syndrome (> 20 Gy)

Neutropenia, thrombocytopenia, lymphopenia, and often pancytopenia then result from the bone marrow aplasia (Figure 3). From the ensuing pancytopenia, the patient may experience increased complications such as sepsis, hemorrhage, and impaired wound healing if there is concomitant trauma.

ARS and Dose

The clinical syndromes that result from radiation exposure occur within a predictable range of doses after whole-body or significant partial-body exposure.

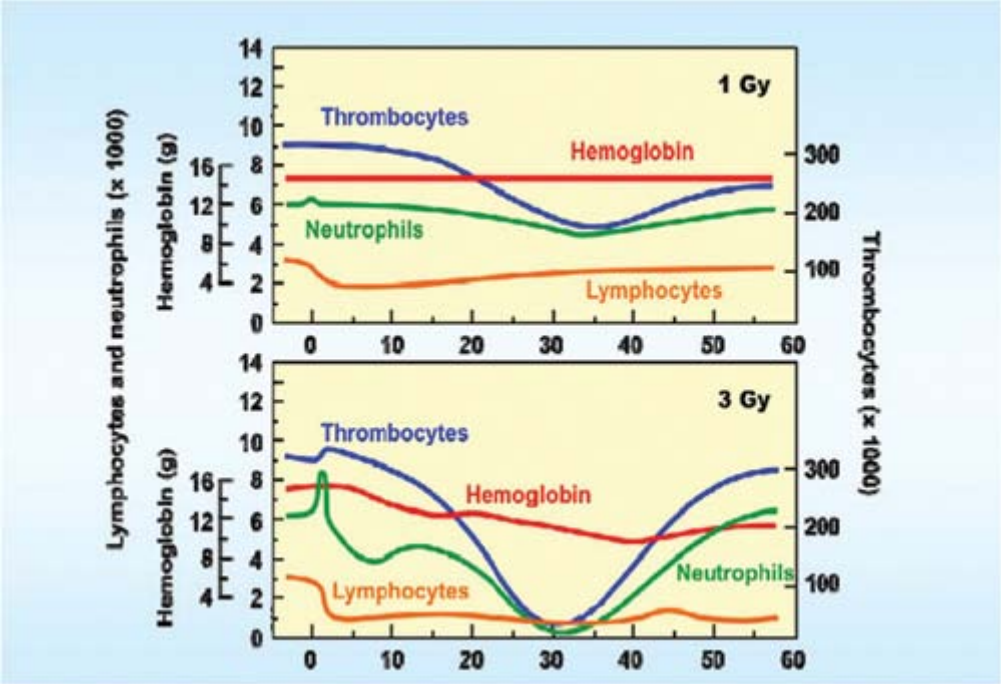


Figure 3. Hematopoietic effects of ionizing radiation. ▲

Hematopoietic Syndrome

Because of their rapid cell turnover, hematopoietic cells in the bone marrow are among the most radiation-sensitive cells in mammals. While significant partial-body or whole-body radiation exposures > 1 Gy define the threshold of the hematopoietic syndrome, it generally is not clinically significant below 2 Gy. Because mitotically active hematopoietic progenitors are unable to divide after a whole-body exposure > 2–3 Gy, a hematologic crisis results in the ensuing weeks and defines the hematopoietic syndrome. At higher doses, additional organ toxicities will occur and significantly complicate management. Consequent to the radiation exposure, lymphopenia, bone marrow atrophy, pancytopenia, and sequelae of infection, bleeding, and poor wound healing occur. All of these contribute to lethality.

The duration of neutropenia may be prolonged, requiring long-term administration of hematopoietic growth factors, blood product support, and antibiotics. Patients with burns and/or wounds often suffer from poor wound healing, bleeding, and infection because of hematopoietic suppression.

Modern supportive care can significantly prolong survival. The mean lethal dose of radiation required to kill 50% of humans at 60 days (LD50/60) is approximately 3.5–4 Gy in persons managed without significant supportive care. The LD50/60 can be increased to 5–6 Gy when antibiotics and transfusion support are provided. The LD50/60 may be extended to 6-8 Gy with early initiation of colony-stimulating factors (CSFs) and optimized care in the intensive care unit (ICU).

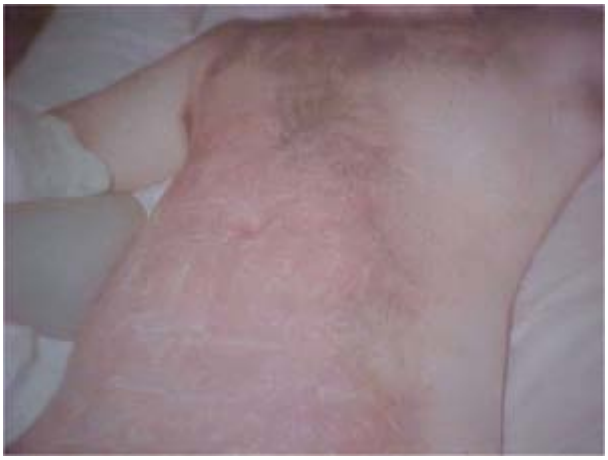


Figure 4. ARS and cutaneous injury with dry desquamation. ▲

Casualties whose radiation dose is most amenable to treatment will be those who receive between 2 and 6 Gy. The primary goal of medical therapy is to shift the survival curve to the right by about 2–3 Gy. Many casualties whose dose exceeds 6–8 Gy also will have significant blast and thermal injuries that will preclude survival when combined with their radiation insult (Figure 4). The successful administration of supportive care is dependent on maintenance of a surviving fraction of stem cells capable of spontaneous regeneration and on whether the nonhematopoietic injuries are survivable. For the patient to survive, hematopoietic regeneration must result in the production of functionally normal neutrophils and platelets within the critical, clinically manageable period.

Gastrointestinal Syndrome

In the higher dose region 5–6 Gy to 20 Gy, the patient experiences the GI component of ARS along with the hematological syndrome. The vulnerability of the small intestine to radiation is primarily in the rapid cell renewal system of the intestinal villi. Radiation sensitivity to the GI tract occurs primarily because of the high turnover rate occurring within the stem cell and proliferating cell compartment of the intestinal crypt. Prodromal symptoms may include early, severe nausea, vomiting, and watery diarrhea, often within hours post-accident. In the later period of manifest illness, the patient may experience severe diarrhea with or without fever and vomiting. In severe cases, the patient may present with shock and possibly renal failure and cardiovascular collapse.

Additional clinical issues with the radiation-induced GI syndrome include malabsorption of nutrients, significant fluid and electrolyte shifts, GI bleeding, and sepsis from loss of integrity of the villus lining. Once there is depletion of the epithelial cells lining the lumen of the GI tract, intestinal bacterial gain free access to the body, often serving as an initial nidus for gram-negative sepsis. In addition, there can be significant hemorrhage through denuded areas. Death from the gastrointestinal syndrome historically has occurred 8–14 days post-accident. In modern institutions with state-of-the-art intensive medical care, the survival period can be extended considerably, but death usually occurs, often from multiple organ failure.

Neurovascular Syndrome

When the patient has experienced high external dose greater than 20 Gy, the neurovascular syndrome occurs. At these dose levels, the patient often will experience a burning sensation immediately post-exposure, nausea and vomiting within minutes, hyperpyrexia, prostration, hypotension, and neurological signs of ataxia and confusion. Death is inevitable and usually occurs within 24–48 h. Autopsy often shows cerebral edema and multiple organ pathology.

Early transient incapacitation (ETI) also is associated with very high acute doses of radiation. In humans, it has occurred only during plutonium and enriched uranium fuel reprocessing accidents. The lower limit is probably 20–40 Gy. The latent period, a return of partial functionality, is very short, varying from several hours to 1–3 days. Subsequently, a deteriorating state of consciousness with vascular instability and death is typical. Convulsions without increased intracranial pressure may or may not occur.

Personnel close enough to a nuclear explosion to develop ETI most likely would die due to blast and thermal effects. However, aircraft crews conceivably could sustain ETI from a nuclear detonation above the atmosphere without blast or thermal injury. Personnel protected from blast and thermal effects in shielded areas also could sustain such doses. Doses in this range also could result from military operations inside a reactor facility or fuel reprocessing plant where personnel are accidentally or deliberately wounded by a nuclear criticality (chain reaction) event.

Medical Management of ARS

ARS is a sequence of phased symptoms. It is characterized by the relatively rapid onset of nausea, vomiting, malaise, and anorexia. An early onset of prodromal symptoms in the absence of associated trauma suggests a large radiation exposure. The medical management of ARS has two primary goals:

- Hematological support to reduce both the depth and duration of neutropenia and thrombocytopenia.
- Prevention and management of neutropenic fever.

There is a quantitative relationship between the depth of neutropenia and the risk of infectious complications. An absolute neutrophil count (ANC) < 100/mm3 is the greatest risk factor.

Radiation-induced emesis occasionally may be confused with psychogenic vomiting that often results from stress and realistic fear reactions. However, judicious use of the medical history may be helpful to differentiate these cases. It also will be helpful to consider the initial CBC values, particularly the absolute lymphocyte count and whether it decreases over the next 24 hours.

In the case of radiation-induced emesis and for patient comfort, use of oral prophylactic anti-emetics, such as granisetron (Kytril®) and ondansetron (Zofran®), have proven helpful. When possible, early oral feeding is preferred to

intravenous feeding to maintain the immunologic and physiologic integrity of the gut.

The spectrum of infecting organisms and antimicrobial susceptibility patterns varies among institutions and over time. Life-threatening, gram-negative bacterial infections are universal among neutropenic patients, but the prevalence of life-threatening, gram-positive bacterial infections varies greatly among institutions. For neutropenic fever, it is highly recommended that current recommendations of the Infectious Disease Society of America (IDSA) be considered.

Hematopoietic growth factors, such as filgrastim (Neupogen®), a granulocyte colony-stimulating factor (G–CSF), and its long-acting pegylated form (Neulasta®) as well as sargramostim (Leukine®), a granulocyte-macrophage colony-stimulating factor (GM–CSF), are potent stimulators of hematopoiesis and shorten the time to recovery of neutrophils.

The risks of infection and subsequent complications are directly related to the depth and duration of neutropenia. To achieve maximum clinical response, filgrastim or sargramostim should be started 24–72 hours after exposure. This provides the opportunity for maximum recovery. Cytokine administration should continue, with consecutive daily injections, to reach the desired effect of an ANC of 1000/mm^3.

Recommended Dosages for the Use of Cytokines

The following cytokines are choices available for patients expected to experience severe neutropenia.

- **Filgrastim** (G-CSF) 2.5–5 µg/kg/d qd subcutaneously (SC) or the equivalent (100–200 µg/m^2/d)
- **Sargramostim** (GM-CSF) 5–10 µg/kg/d qd SC or (200–400 µg/m^2/d)
- **Pegfilgrastim** (pegG-CSF) 6 mg once SC

Hospital Issues for Management of Severe ARS

- Antibiotic prophylaxis, as well as antiviral and antifungal agents.
- Barrier isolation; GI decontamination.
- Early cytokine therapy.
- Early surgical wound closure and avoidance of unnecessary invasive procedures.
- ARS patients with whole-body dose > 2–3 Gy should be in isolation rooms. Medical personnel should be aware of the need for rigorous environmental control, including possibly laminar flow isolation, strict hand washing, and surgical scrubs and masks for staff.

- Physiological interventions include maintenance of gastric acidity, avoidance of antacids and H2 blockers, use of sucralfate for stress ulcer prophylaxis when indicated to reduce gastric colonization and pneumonia, and early oral enteral feeding when feasible.
- Povidone-iodine or chlorhexidine for skin disinfection and shampoo. Meticulous oral hygiene.

Clinical Example: ARS Triage

Event. An IND has detonated in a major urban environment and hundreds of people are crowding your ED. Your patient has normal vital signs, normal primary and second survey, but has vomited repeatedly, beginning approximately 2 hours post-event.

Solution. Using the simple scoring system from the topic Emergency Response, Triage, the neutrophil to lymphocyte ratio is given for the times below.

Time post-event	N/L ratio
2 h	1.32
4.5 h	15.2
9 h	9.78

N is obtained from WBC × (% neutrophils) and a similar equation for L. From the differential, N/L = (% neutrophils) / (% lymphocytes) because the WBC value cancels in the ratio. So, it is most important to order a differential along with the CBC. Popularization of the N/L ratio in early radiation triage has come from multiple AFRRI scientific staff publications.

Assigning 2 points for emesis gives values of T = 3.32, 17.2, and 11.78 at 2, 4.5, and 9 hours post-exposure. The patient should therefore be referred for more extensive hematological evaluation. Clinical data in this example is from a real patient with 3.5-Gy acute gamma dose from a Co-60 source. Data is courtesy of the Radiation Emergency Assistance Center/Training Site (REAC/TS) Radiation Accident Registry.

▲

Biodosimetry

Biodosimetry is the use of a biological response as an indicator of radiation dose. Cytogenetic biodosimetry is considered the gold standard for determination of patient whole- or partial-body radiation dose. For biodosimetry guidance call AFRRI at 301-295-0530 or DSN 295-0530.

Early-Response Multi-Parameter Biodosimetry

No single assay is sufficiently robust to address all potential radiation scenarios, including management of mass casualties and diagnosis for early medical treatment. Recommendations for use by first responders and first receivers involve a prioritized multiple-assay biodosimetric-based strategy. The National Council on Radiation Protection & Measurements (NCRP) Commentary No. 19 (NCRP, 2005) recommends multi-parameter triage (i.e., time to vomiting, lymphocyte kinetics, and other biodosimetry and biochemical indicators) as the current best early assessment of a victim's absorbed dose. Early, approximate assessment of dose is not intended to replace more established, but more time-consuming, techniques of health physics dose reconstruction.

Table 3. Multiple Parameter Biodosimetry. ▲

Dose, Gy	% emesis	Median onset of emesis (h)	Absolute lymphocyte count; % of normal in first 24 h	Relative increase in serum amy-lase, day 1	Number of dicentrics per 50 metaphases
0	-	-	100	1	0.05–0.1
1	19	-	88	2	4
2	35	4.6	78	4	12
3	54	2.6	69	6	22
4	72	1.7	60	10	35
5	86	1.3	53	13	51
> 6	90–100	1.0	< 47	> 15	-

From Table 3, it is evident that emesis within 1–2 h is particularly serious while a drop in lymphocyte count to 1/2 or 1/3 of baseline values within 24 hours signals a potentially lethal situation. After 24 hours, increases in serum amylase are also potentially confirmative. As noted below, early, rapid deployment, high-throughput cytogenetic dosimetry is expected to be very valuable in triage of large numbers of people. Conversely, from the TE data, if a patient has not

vomited in 8–10 h, then any dose is very likely less than 1 Gy and he/she can be moved to outpatient facilities.

Consensus biodosimetric guidelines include the following measurements:

- Signs and symptoms
- Radioactivity assessment
- Hematology
- Personal and area dosimetry
- Cytogenetics
- EPR-based dose assessment
- Serum amylase activity, C-reactive protein, FLT-3 ligand, citrulline, blood protein assays, etc.

Cytogenetic Biodosimetry

Cytogenetic biodosimetry is a widely accepted method for dose assessment following acute whole- or partial-body irradiation. However, the standard method of scoring 500–1000 metaphase spreads requires about 4–5 days, including timely transport to the laboratory, processing, reading and scoring the sample, and providing an analysis. Most labs will therefore be able to process no more than 100–200 samples per day.

Automated metaphase finders are currently available and in use. In addition, research is underway to score only 50–100 metaphases in order to obtain a cytogenetic triage dose estimate. This is generally satisfactory to guide clinical treatment decisions.

Table 4. Physician Guidance on Choice of Biodosimetry Methods. ▲

Dose range (Gy)	Dosimetry method	Clinical symptoms
0.1 – 1	Dicentric/PCC	None to slight decrease in blood count
1 – 3.5	Lymphocyte depletion kinetics/dicentrics/PCC	Mild to severe bone marrow damage
3.5 – 7.5	Lymphocyte depletion kinetics/PCC	Pancytopenia, mild to moderate GI damage at 5–6 Gy
7.5 – 10	Lymphocyte depletion kinetics/PCC	Bone marrow and GI damage
> 10	PCC	GI, neurological, and cardiovascular damage

Accepted approaches to cytogenetic dosimetry include dicentric analysis, cytokinesis block micronucleus assay, premature chromosome condensation, electron paramagnetic resonance, and molecular markers in body fluids and tissues. AFRRI guidance for the most useful multi-parameter biodosimetric techniques is provided in Table 4.

Dicentric Analysis

Dicentric chromosomes are formed when broken segments of irradiated chromosomes rejoin into chromosomes with two centromeres. The number of these dicentric chromosomes is a precise measure of dose. In the dicentric assay, stimulated lymphocytes are arrested and fixed onto slides in metaphase where the chromosomes are condensed. The metaphase spreads are then analyzed for the presence of dicentric and ring chromosomes (Figure 5).

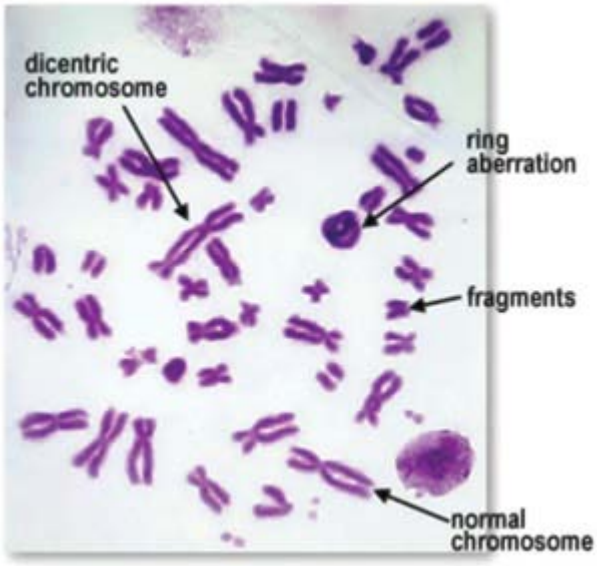


Figure 5. Irradiated lymphocyte chromosomes fixed on a slide in the metaphase stage of mitosis. ▲

Based on calibration curves produced from in vitro exposures, a dose estimate can be made according to the number of dicentrics and rings detected per cell. This assay is generally accepted as the most specific and sensitive (0.2 Gy) method for determining doses from recent exposures to ionizing radiation (i.e., within days to ~ 6 months). This assay can determine if the body received a homogeneous dose distribution. However, techniques also exist to determine if the dose is nonhomogeneous.

The usefulness of this assay is greatly reduced for measuring dose received more than 6 months before the assay because of the half-life of cells with dicentric or ring aberrations.

Radiation-induced chromosome damage is relatively unstable and is eliminated from the peripheral blood lymphocytes as the lymphocyte pool repopulates. More persistent, stable translocations can be measured using fluorescence in situ hybridization (FISH). In this method, any number of chromosomes can be labeled with chromosome-specific fluorescently labeled DNA probes, allowing exchanges between chromosomes to be identified using fluorescent microscopy. The stability of these translocations is thought to remain high over decades. The approach has been used for dosimetry reanalysis of WWII Hiroshima survivors and in civilian radiation events that happened decades ago.

Cytokinesis Block Micronucleus Assay

The cytokinesis block micronucleus assay is an alternative for biological dosimetry. Micronuclei are formed during cell division when a whole chromosome or an acentric chromosome fragment does not integrate into the nucleus of the daughter cell. When cytokinesis is inhibited, binucleated cells result after the first mitotic division, and these binucleated cells can be scored for the presence of micronuclei. This assay is faster to score and requires less skilled technical staff than dicentric analysis, due to the simple shape of the micronuclei. The lower detection level is about 0.3 Gy.

Premature Chromosome Condensation

One limitation of assays requiring lymphocyte stimulation is that cells receiving higher radiation doses also experience a cell cycle delay and may never reach mitosis. This can result in a large underestimation of the absorbed dose. Chromosomes, however, can be forced to condense prematurely by fusing human lymphocytes with Chinese hamster ovary (CHO) mitotic cells in the presence of polyethylene glycol (PEG). This technique allows measurement of chromosomal aberrations without the requirement for damaged cells to reach mitosis. Because this assay can better measure the proportion of exposed cells, it is particularly useful in detecting partial-body exposures and small localized exposures.

Electron Paramagnetic Resonance (EPR)

Exposure of humans to ionizing radiation results in radiation-induced changes that can be measured and, depending on the absorbed dose, quantified. The use of EPR for biodosimetry is based on the capability of the technique to provide specific and sensitive measurement of unpaired electrons in solid tissue, which are created in proportion to the absorbed dose. The lifetimes of these electrons are very short (nanoseconds) in aqueous systems, such as most biological tissues, but can be extremely stable in non-aqueous media, including teeth, bone, fingernails, and hair. EPR has been used for in vitro analyses of exfoliated teeth to measure doses in populations from Japan and the former Soviet Union. The effectiveness of EPR has been well demonstrated.

Molecular Markers in Body Fluids and Tissues

Molecular markers (biomarkers) represent underlying changes in physiology arising from physical damage (e.g., cell lysis and the release of intracellular proteins into the circulation, oxidation by-products or DNA breakage), underlying changes in biochemistry (e.g., the presence of new metabolites or changes in levels of key gene products), and/or changes in cellular composition

of tissues. These markers include molecules as diverse as proteins and small molecule metabolites.

Within minutes to hours after exposure to ionizing radiation, proteins are modified and activated, and large-scale changes occur in the gene expression profiles involving a broad variety of cell-process pathways. There are approximately 90 known proteins that show changes in expression or undergo post-translational modifications after exposure to ionizing radiation. Some of these change in a dose-dependent fashion. Use of biochemical markers in a multi-parameter assay represents an exciting new development in radiation dosimetry.

AFRRI Biodosimetry Capability

The BAT program (Figure 6) was developed by AFRRI scientists as a tool to deliver diagnostic information (clinical signs and symptoms, physical dosimetry, etc.) to Federal healthcare providers responsible for the management of radiation casualties. It is designed primarily for early use after a radiation incident and permits collection, integration and archiving of data obtained from patients accidentally exposed to ionizing radiation. Structured software facilitates collection of relevant data, which then gives a dose estimate. This can guide medical management.

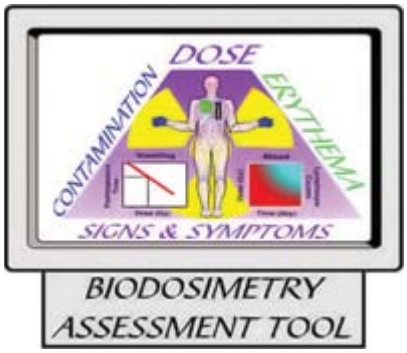


Figure 6. Logo for the AFRRI Biodosimetry Assessment Tool software program. ▲

Besides the BAT software, AFRRI offers a number of other exposure assessment tools. AFRRI Form 330 is a one-page form for gathering patient emergency medical information in a field setting. The AFRRI Biodosimetry Worksheet (AFRRI Form 331) is a six-page form to record patient exposure data. These forms are available from the AFRRI website. In particular, BAT input is captured as well as METREPOL (Medical Treatment Protocols) data and the use of molecular biomarkers.

Radiological Assessment Triage (FRAT) Software for Palm PDA and Other Handheld Devices

The new AFRRI First-responders Radiological Assessment Triage (FRAT) software application will enable first responders to triage suspected radiation casualties based on the initial, or prodromal features listed in the Emergency Radiation Medicine Response—AFRRI Pocket Guide. FRAT is being developed initially for the Palm operating system for personal digital assistant (PDA) devices (Figure 7) and may eventually be available for other PDA devices.

With minimum text entry, FRAT will provide (1) signs and symptoms, (2) blood lymphocyte counts, and (3) dosimetry data.The program will assess the multi-parameter triage dose or the exposure without an assigned dose, or it will indicate there is no evidence of overexposure. Additional FRAT output features include triage dose-specific messages addressing (1) reliability and diagnostic information, (2) hospitalization estimations, and (3) mortality projections.

Figure 7. The Palm PDA is the initial platform for the FRAT software application. ▲

▲

Medical Management of Skin Injury

Dose and Clinical Signs

Acute local irradiation events may occur separately or coexist with ARS. Radiation injury to the skin is common in the civilian sector where many radiation devices are in industrial use. Deterministic thresholds exist as follows for certain clinical signs.

- **3 Gy** for epilation, beginning 14–21 days post-incident.
- **6 Gy** for erythema, often transient soon post-incident, with secondary erythema 14–21 days thereafter. The pathophysiology for erythema includes arteriolar construction with capillary dilation and local edema. Erythema may occur in a few hours post-accident (primary erythema) or come and go in waves.
- **10–15 Gy** for dry desquamation of the skin secondary to radiation to the germinal layer, usually > 20 days post-incident. Dry desquamation results from response of the germinal epidermal layer to radiation. There is diminished mitiotic activity in cells of the basal and parabasal layers with thinning of the epidermis and desquamation of large macroscopic flakes of skin.
- **20–50 Gy** for wet desquamation (partial thick-

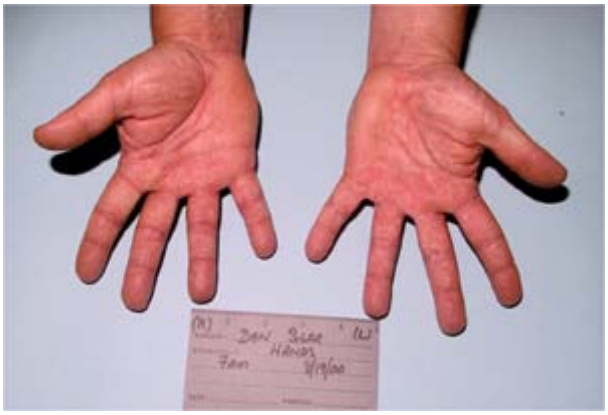


Figure 8. X-ray accident, 0 days post-incident. ▲

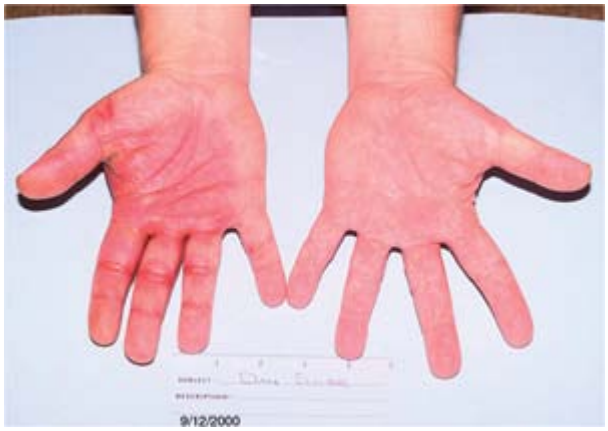


Figure 9. Twenty-four days post-incident. ▲

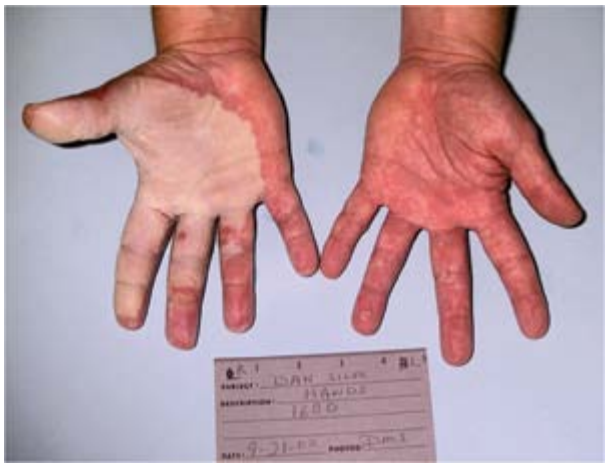


Figure 10. Thirty-three days post-incident. ▲

ness injury) at least 2–3 weeks post-exposure, depending upon dose. In moist desquamation, microscopically, one finds intracellular edema, coalescence of vesicles to form macroscopic bullae, and a wet dermal surface, coated by fibrin.

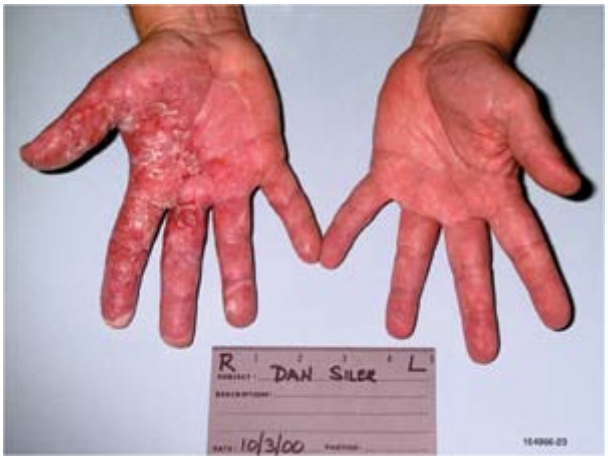


Figure 11. Forty-five days post-incident, post-debridement. ▲

- **> 50 Gy** for overt radionecrosis and ulceration secondary to endothelial cell damage and fibrinoid necrosis of the arterioles and venules in the affected area. A cutaneous syn-drome, arising from high-level whole-body irradiation along with local injury, also has been described by various authors.

Clinically, within the first week post-accident, the patient is asymptomatic, with possibly an early wave of transient erythema. In week 2, true erythema develops along with progressive epilation, suppression of sweating, and diminished sebaceous gland secretion. In week 3, the patient often presents with warm skin that is edematous, painful when touched, with occasional severe pruritis, and symptoms that are generally limited to the radiation field. By week 4, overt dry or wet desquamation has evolved in a dose-dependent manner in skin exposed to the radiation field. The sequence of local radiation injury is shown in REAC/TS Figures 8–11.

Treatment

The usual U.S. experience in partial-body exposure has been high-level, low linear energy transfer exposure to relatively small areas of skin, either from sealed sources or from x-ray or accelerator accidents (Figure 12). For a clinically significant lesion to occur generally requires that more than 10 cm^2 of the basal layer of skin have been irradiated. The Centers for Disease Control and Prevention (CDC) recently published physician guidelines for grading cutaneous radiation injury.

- **Grade I:** > 2 Gy
- **Grade II:** > 15 Gy
- **Grade III:** > 40 Gy

The medical history is particularly important in diagnosis of the extent of partial-body injury because signs and symptoms generally take days to weeks to manifest. In addition, serial color digital photographs are crucial, possibly along with drawings of the lesion. These allow more precise documentation of the evolution of cutaneous necrosis.

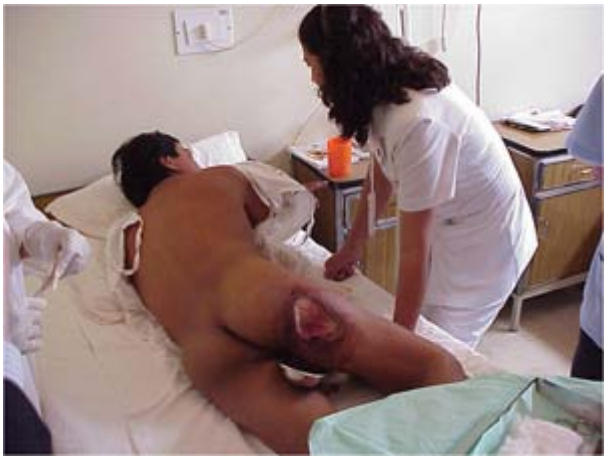


Figure 12. Extensive lesion from Ir-192 source (IAEA). ▲

In the United States, diagnosis of high-level skin dose generally has been estimated by observing the serial evolution of symptoms. However, additional diagnostic tools used have included cytogenetic dosimetry, position-emission tomography (PET) scans, magnetic resonance imaging (MRI), ultrasound visualization of the lesion, and Doppler or laser flow profiles. The key management issues with cutaneous radiation injury are infection control, state-of-the-art wound care, and appropriate pain management. Also, it often is very helpful to obtain the services of a plastic or reconstructive surgeon early in the clinical course.

Radiation-induced skin and organ fibrosis and late skin radionecrosis are delayed complications that usually are considered irreversible (Figure 13). Typical medical management includes eliminating local and general aggravating factors and controlling acute and chronic inflammation with steroids.

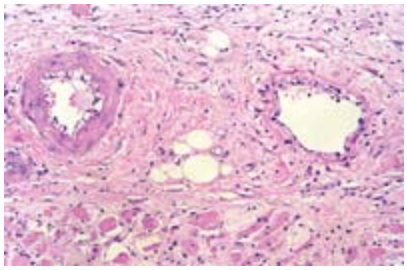


Figure 13. Histopathology showing radiation-induced fibrosis of arteriole, left (IAEA). ▲

Radiation necrosis can be managed based on the etiology.

- Anti-inflammatory treatment with topical corticosteroids
- Vascular therapy with hyperbaric oxygen (HBO) and pentoxifylline (Trental®, PTX) or PTX-vitamin E combination
- Wound management and surgical guidance by physicians experienced in the management of chronic vascular injury

Clinical Example: Multi-Parameter Analysis of Partial-Body Radiation Injury

A new Cs-137 source (100 Ci) is placed in a restaurant. Unaware of this fact, an individual visits the restaurant, sees a metallic object, and puts it in his pocket. Two days later, he reports to the nearest hospital complaining of redness to his right buttock and mild tingling in the area. As the emergency physician, you see an apparently healthy 26-year-old male with normal initial vital signs. Moderate vomiting begins 2 hours later. On history, the patient reports the object. It is produced and sets off a portal monitor in the ED. Appropriate officials are notified.

Blood is drawn for a CBC with differential and q 6 h, and the patient is admitted for observation. An initial consult is obtained from a plastic and reconstructive surgeon as well as from a hematologist.

It now appears to attending physicians that a major radiation event may have occurred. A medical consult is requested from AFRRI. Repeat CBCs show decreasing lymphocytes and a slightly rising neutrophil count. Consultant physicians order a multi-parameter partial-body irradiation blood panel and chromosome biodosimetry as indicated. The patient experiences nausea multiple times, and granisetron, 1 mg, is administered IV q 12 h prn (*pro re nata;* as needed).

A multi-parameter blood panel drawn the next day shows the following results: ↓ lymphocytes; ↑ amylase × 4 (450 IU/L); ↑ N/L ratio; FLT-3, 100 pg/mL (↑ × 10); ↑ CRP 100 µg/mL (↑ × 100); normal citrulline; ↑ × 10 IL-6 and ↑ × 30 gCSF; cytogenetic results, estimated 3.5 Gy whole-body dose; Poisson dispersion index, 1.35.

The Poisson dispersion index is defined as the variance of the statistical distribution divided by the mean, which should equal unity in a perfect Poisson process. This significant deviation is strongly suggestive of nonuniform partial-body injury. In the United States, analysis of overdispersion of dicentric chromosomes from the expected Poisson distribution most commonly employs the Qdr technique of Sasaki.

Conclusion

Early ARS with significant partial-body irradiation. Institute supportive measures and cytokine therapy as medically indicated. Monitor for impending neutropenia, thrombocytopenia, and neutropenic fever. Institute IDSA guidelines for antibiotic therapy when appropriate. Consider platelet transfusion as medically indicated.

▲

Medical Management of Internally Deposited Radionuclides

Internal Contamination

Internal contamination will occur when unprotected personnel ingest, inhale, or are wounded by radioactive material. Any externally contaminated casualty who did not have respiratory protection should be evaluated for internal contamination. Internal contamination is more likely if significant contamination is found on the face or around or in the nostrils.

Medical management is specific and isotope-dependent; consequently, identifying the isotope is crucial. Metabolism and elimination kinetics of the nonradioactive analog determine the metabolic pathway of the radionuclide. The major routes of intake are inhalation, ingestion, absorption through an open contaminated wound, and transdermal absorption. Dissolution of uranium from embedded depleted uranium (DU) shrapnel also has been noted.

Forces operating in a theater with nuclear power reactors may be at risk if enemy forces target those reactors and their containment facilities. Downwind service members could internalize significant amounts of iodine-131 and other fission by-products. MOPP equipment will provide more than adequate protection from particulate radiological contamination. The standard NBC (nuclear, biological, chemical) protective mask will prevent inhalation of any particulate contamination, but not radioactive gases.

After prolonged use in a contaminated area, filters should be checked with a radiation instrument prior to disposal. Normal hospital barrier clothing also will provide satisfactory emergency protection for hospital personnel attending wounded and contaminated soldiers.

Approaches to Medical Management

The medical management of internal contamination falls into several major categories:

- Reducing and/or inhibiting absorption of the isotope in the GI tract. Examples: Use gastric lavage or cathartics.
- Blocking uptake to the organ of interest. Example: Within 4 hours of exposure, administer potassium iodide (KI) to block uptake of radioactive iodine by the thyroid.
- Diluting the isotope. Example: Increase fluid hydration for internal tritium contamination.

- Altering the chemistry of the substance. Example: Prevent deposition of uranium carbonate complexes in the renal tubules by use of sodium bicarbonate.
- Displacing the isotope from receptors. Example: Administer stable iodine to displace 99mTc.
- Using traditional chelation techniques. Example: Administer DTPA for internal deposition of plutonium.
- Excising radionuclides from wounds early to minimize absorption.
- Using bronchoalveolar lavage for severe cases of insoluble inhaled particles. This rarely used technique would be expected only in a case with a very large lung burden of an insoluble alpha emitter such as plutonium.

There are over 8000 isotopes, but the military and civilian sectors consider only 10–15 important with regard to terrorism and industrial accidents. Certain isotopes fall into general categories:

- **University seven:** H-3 (tritium), C-14, P-32, Co-60, I-125, I-131, Cf-252. Used in medicine and for isotopic labeling in biochemistry laboratories.
- **Industrial three:** Ir-192, Cs-137, Co-60. Ir-192 is widely used in industrial radiography to photograph large objects such as oil pipes, airplane wings, etc. Cs-137 and Co-60 are used in industry because of their penetrating gamma rays and are considered prime agents for terrorism events.
- **Military four:** Tritium (H-3), U-235, Pu-239, and Am-241. Isotopes primarily used in the weapons complex, both in the Department of Energy (DOE) system and in the military.
- **Fission products:** Products of a weapon explosion, either an IND or a weapon of full or significant yield. Often volatile and pose a significant risk to the populace.

NCRP 161 (2009) is widely considered an important reference document for decorporation therapy in patients with internal deposition of radionuclides. Tables 5 and 6 are adapted from that guidance.

Therapy for Specific Radionuclides

This section provides (1) recommendations for decorporation therapy for specific radionuclides, and (2) drug information for treatment. Table 5 summarizes treatment recommendations for various radionuclides of concern in the medical management of internal contamination. Table 6 provides dose schedules for drug or treatment modalities.

Table 5. Decorporation Therapy Recommendations in the USA for Radionuclides of Concern (NCRP Report 161, 2009). ▲

Radionuclides of	Treatment (*preferred Rx)
Actinium (Ac)	Consider DTPA.
Americium (Am)	DTPA
Antimony (Sb)	BAL*, penicillamine
Arsenic (As)	BAL*, DMSA
Barium (Ba)	Ba, Ca therapy. See NCRP 161.
Berkelium (Bk)	DTPA
Bismuth (Bi)	BAL, penicillamine, DMSA*
Cadmium (Cd)	DMSA*, DTPA, EDTA
Californium (Cf)	DTPA
Calcium (Ca)	Ba, Ca therapy. See NCRP 161.
Carbon (C)	No treatment available
Cerium (Ce)	DTPA
Cesium (Cs)	Prussian blue
Chromium (Cr)	DTPA*, EDTA (Antacids are contraindicated.)
Cobalt (Co)	DMSA, DTPA*, EDTA, NAC
Copper (Cu)	EDTA, penicillamine*, trientine
Curium (Cm)	DTPA
Einsteinium (Es)	DTPA
Europium (Eu)	DTPA
Fission products (mixed)	Management depends on predominant isotopes present at time. Early: iodine Late: strontium, cesium, and others
Fluorine (F)	Aluminum hydroxide
Gallium (Ga)	Consider penicillamine.
Gold (Au)	BAL*, penicillamine
Indium (In)	DTPA
Iodine (I)	Potassium iodide (KI)*, propylthiouracil, methamizole. For patients with iodine sensitivity, consider potassium perchlorate.
Iridium (Ir)	Consider DTPA*, EDTA.
Iron (Fe)	Deferoxamine (DFOA)*, deferasirox, DTPA, DFOA and DTPA together
Lanthanum (La)	DTPA
Lead (Pb)	DMSA*, EDTA, EDTA with BAL
Manganese (Mn)	DFOA, DTPA*, EDTA
Magnesium (Mg)	Consider strontium therapy.
Mercury (Hg)	BAL*, EDTA, penicillamine, DMSA
Molybdenum (Mo)	Limited clinical experience
Neptunium (Np)	Consider DFOA and/or DTPA.
Nickel (Ni)	BAL*, EDTA

Radionuclides of	Treatment (*preferred Rx)
Niobium (Nb)	DTPA
Palladium (Pd)	Penicillamine*, DTPA
Phosphorus (P)	Phosphorus therapy
Plutonium (Pu)	DTPA*, DFOA, EDTA, DTPA and DFOA together
Polonium (Po)	BAL*, DMSA, penicillamine
Potassium (K)	Diuretics
Promethium (Pm)	DTPA
Radium (Ra)	Ra, Sr therapy
Rubidium (Rb)	Prussian blue
Ruthenium (Ru)	DTPA*, EDTA
Scandium (Sc)	DTPA
Silver (Ag)	No specific therapy. Consider gastric lavage and purgatives.
Sodium (Na)	Diuretic and isotopic dilution with 0.9% NaCl
Strontium (Sr)	See Table 5. Radium and strontium therapy.
Sulfur (S)	Consider sodium thiosulfate.
Technetium (Tc)	Potassium perchlorate
Thallium (Tl)	Prussian blue
Thorium (Th)	Consider DTPA.
Tritium (3H)	Force fluids; Water diuresis*
Uranium (U)	Bicarbonate* to alkalinize the urine. Consider dialysis
Yttrium (Y)	DTPA*, EDTA
Zinc (Zn)	DTPA*, EDTA, zinc sulfate as a diluting agent
Zirconium (Zr)	DTPA*, EDTA

KI Blockage of the Thyroid

Children are particularly susceptible to thyroid cancer following exposure to radioactive iodine. The uptake of radioactive iodine should be blocked by administering oral potassium iodide (KI) within 4 hours of exposure (Table 7).

Tritium

Tritium (hydrogen-3 or 3H) is a hydrogen isotope with a nucleus composed of two neutrons and one proton. Tritium is the only radioactive isotope of hydrogen, decaying with emission of a very low-energy electron. It is used in nuclear weapons, in luminescent gun sights, and in muzzle-velocity detectors. It is unlikely to be a radiation hazard except in a closed space.

Table 6. Dose Schedules for Drug or Treatment Modalities. ▲

Treatment	Dosage
Acetylcysteine (NAC)	FDA does not specify age. IV 300 mg/kg in 50% dextrose in water over 24 hours.
Deferoxamine (DFOA)	FDA does not specify age. Deferoxamine mesylate injectable; IM is preferred. 1 g IM or IV (2 ampules) slowly (15 mg kg-1 h-1); repeat as indicatged as 500 mg IM or IV q 4 h x 2 doses; then 500 mg IM or IV q 12 h for 3 days.
Dimercaprol (BAL)	FDA does not specify age. IM 300 mg per vial for deep IM use, 2.5 mg-1 kg (or less) q 4 h for 2 days, then twice daily for 1 day, then daily for days 5–10.
Diethylenetriaminepentaacetate (DTPA, calcium or zinc)	**Adults:** IV 1 g in 5 mL IV push over 3–4 minutes, or IV infusion over 30 minutes, diluted in 250 mL of 5% dextrose in water, Ringer's lactate, or normal saline (NS). **Nebulized inhalation:** 1 g in 1:1 dilution with sterile water or NS. **Children under 12 years:** 14 mg kg–1 IV as above, not to exceed 1 g. **IM:** 1 g can be given with procaine to reduce pain (not FDA approved).
Edetate calcium disodium (EDTA)	FDA does not specify age. Ca-EDTA; 1000 mg m–2 d–1 added to 500 mL D5NS infused over 8–12 hours.
Penicillamine	FDA does not specify age. Oral: 250 mg daily between meals and at bedtime. May increase to 4 or 5 g daily in divided doses.
Phosphorus therapy: Potassium phosphate, dibasic	**Oral:** 250 mg phosphorus per tablet. **Adults:** 1–2 tabs oral four times daily with full glass of water each time, with meals and at bedtime. **Children over 4 years:** 1 tab orally four times daily.
Potassium iodide (KI)	**Oral:** Tablets or liquid. Drug dose varies between 16 mg and 130 mg daily depending on age, thyroid exposure level, and whether pregnant or lactating.
Propylthiouracil (PTU)	FDA does not specify age. Oral: 50 mg tabs, 2 tabs three times daily for 8 days.
Prussian blue	**Oral:** Adults and adolescents 3 g three times daily. Children 2–12 years: 1 g three times daily.
Sodium bicarbonate (for uranium only)	Oral or IV.
Radium and strontium therapy	**Aluminum hydroxide.** PO; 60–100 mL once. 10% calcium chloride suspension. Adults: IV; 200 mg to 1 g every 1–3 d, slow IV, not to exceed 1 mL min–1. **Calcium gluconate.** PO: 10 g powder in a 30-cc vial; add water and drink.
Succimer (DMSA) (Chemet®)	FDA-approved pediatric dosing: Start dosage at 10 mg kg–1 or 350 mg m–2 oral q 8 h for 5 days. Reduce frequency of administration to 10 mg kg–1 or 350 mg m–2 q 12 h (two-thirds of initial daily dosage) for an additional 2 weeks of therapy. A course of treatment lasts 19 days.
Water diuresis	**Oral:** Fluids more than 3–4 L d–1.

Table 7. Potassium Iodide Recommended Doses. ▲

Adults ›40 years of age with thyroid exposure ≥ 5 Gy (500 rad)	130 mg d–1
Adults 18–40 years of age with thyroid exposure ≥ 0.1 Gy (10 rad)	130 mg d–1
Pregnant or lactating women with thyroid exposure ≥ 0.05 Gy (5 rad)	130 mg d–1
Children and adolescents 3–18 years of age with thyroid exposure ≥ 0.05 Gy (5 rad)	65 mg d–1
Infants 1 month to 3 years of age with thyroid exposure ≥ 0.05 Gy (5 rad)	32 mg d–1
Neonates from birth to 1 month with thyroid exposure ≥ 0.05 Gy (5 rad)	16 mg d–1

Tritium has certain characteristics that present unique challenges for dosimetry and for health-risk assessment. For example, in the gas form, tritium can diffuse through almost any container and, in the oxide form, cannot be detected by commonly used survey instruments. In the environment, tritium is taken up by all hydrogen-containing molecules and therefore distributes widely on a global scale. Tritiated water, HTO, is taken easily into the body by inhalation, ingestion, or transdermal absorption. It is instantaneously absorbed and mixes with body water.

Dose to total body water is therefore the critical issue in the management of tritium accidents. Tritium also can be incorporated into organic molecules in the body to form longer-lasting, organically bound tritium.

Medical management of tritium intake is directed primarily to increasing body water turnover. Tritium is almost never a significant radiation hazard. It is excreted in urine, and urine samples will be positive within an hour of significant exposure. No adverse health effects have been reported from a single, acute exposure.

For accident dosimetry purposes, tritium retention is assumed to have a half life of approximately 10 days. Single exposures are treated by increasing oral fluid intake. This has the dual value of diluting the tritium and increasing excretion by physiological mechanisms.

An increase in oral fluids of 3–4 liters/day reduces the biological half-life of tritium by a factor of 2–3 and therefore reduces whole-body dose in the same proportion. Bioassay is generally accomplished by 24-hour urine collections that are analyzed by liquid scintillation counting.

In a high-level exposure, intravenous hydration, management of fluid intake and output, and use of diuretics is a possible modality for increasing turnover of body water, but historically, this rarely has been necessary. In all cases, care must be taken to avoid water intoxication.

Depleted Uranium

Depleted uranium (DU) is neither a radiological nor a chemical threat. It is not a weapon of mass destruction. It is addressed in this manual for medical treatment issues. DU is defined as uranium metal in which the concentration of uranium-235 has been reduced from the 0.7% that occurs naturally to a value less than 0.2%. DU is a heavy, silvery white metal, a little softer than steel, ductile, and slightly paramagnetic. In air, DU develops a layer of oxide that gives it a dull black color.

DU is useful in kinetic energy penetrator munitions as it is also pyrophoric and literally ignites and sharpens under the extreme pressures and temperatures generated by impact (Figure 14). As the penetrator enters the crew compartment of a target vehicle, it brings with it a spray of molten metal as well as shards of both penetrator and vehicle armor (spall), any of which can cause secondary explosions in stored ammunition.

Figure 14. DU kinetic energy penetrator. ▲

After such a penetration, the interior of the struck vehicle will be contaminated with DU dust and fragments and with other materials generated from armor and burning interior components. Consequently, casualties may exhibit burns derived from the initial penetration as well as from secondary fires. They also may have been wounded by and retain fragments of DU and other metals. Inhalation injury may occur from any of the compounds generated from metals, plastics, and components fused during the fire and explosion.

Wounds that contain DU may develop cystic lesions that solubilize and allow the absorption of the uranium metal. This was demonstrated in Persian Gulf War veterans who were wounded by DU fragments. Studies in scientific models have demonstrated that uranium from such wounds will slowly be distributed systemically with primary deposition in the bone and kidneys. DU emits alpha, beta, and weak gamma radiation. Due to the metal's high density, much of the radiation never reaches the surface of the metal. It is thus self-shielding. Uranium-238, thorium-234, and protactinium-234 will be the most abundant isotopes present in a DU-ammunition round and its fragments.

Intact DU rounds and armor are packaged to provide sufficient shielding to stop beta and alpha radiation. Gamma-radiation exposure is minimal although crew exposures could exceed limits for the U.S. general population (1 mSv) after several months of continuous operations in an armored vehicle completely loaded with DU munitions. The maximum annual exposure allowed for U.S. radiation workers is 50 mSv.

Internalization of DU through inhalation of particles in dust and smoke, ingestion of particles, or wound contamination presents potential radiological and toxicological risks. Single exposures of 1–3 µg of uranium per gram of kidney

can cause irreparable damage to the kidneys. Skeletal and renal deposition of uranium occurs from implanted DU fragments. The toxic level for long-term chronic exposure to internal uranium metal is unknown. The heavy-metal hazards are possibly more significant than the radiological hazards. For insoluble compounds, the ingestion hazards are minimal because most of the uranium will be passed through the GI tract unchanged.

Sodium bicarbonate makes the uranyl ion less nephrotoxic. Tubular diuretics may also be beneficial. DU fragments in wounds should be removed whenever possible. Laboratory evaluation should include urinalysis, 24-hour urine for uranium bioassay, serum blood urea nitrogen, creatinine, beta-2-microglobulin, creatinine clearance, and liver function studies.

All fragments larger than 1 cm in diameter should be removed if the surgical procedure is practical. Extensive surgery solely to remove DU fragments is NOT indicated. If DU contamination is suspected, the wound should be thoroughly flushed with irrigating solution. If a DU fragment (Figure 15) is excised after wound healing has occurred, care should be taken to avoid rupturing the pseudocyst that may be encapsulating the DU fragment. In experimental studies, this cyst is filled with a soluble uranium fluid. Capsule tissue often is firmly adhered to the remaining metal fragment.

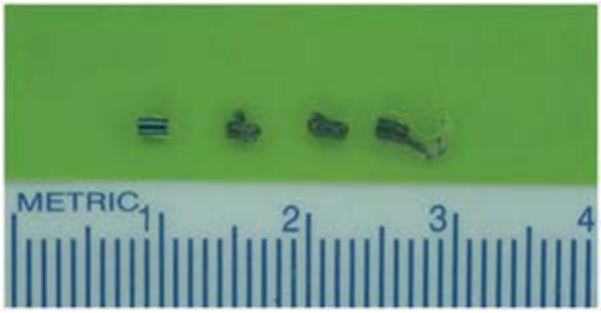


Figure 15. DU fragments. ▲

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Other Injuries from Nuclear Weapons

Nuclear weapons cause traumatic injuries as well as injuries due to radiation. These injuries arise from high pressures and winds, the flash from the nuclear detonation, a thermal pulse, and secondary fires.

Immediate treatment should focus on the trauma rather than radiation effects. Surgical priorities for acute or life-threatening injury must precede any treatment priority for associated radiation injury. In combined injury events, all surgical procedures must be accomplished as quickly as possible and wound closure must be completed within 36–48 hours from irradiation.

Blast Injury

Two types of blast forces occur in a nuclear detonation: direct blast wave overpressure forces and indirect blast wind drag forces. Blast wind drag forces produce casualties due to flying debris (missiles) or to casualties being blown against objects and structures in the environment (translational injuries). Overpressure forces are strong enough to displace large objects such as vehicles or to cause buildings to collapse, causing serious crush injuries comparable to those seen in earthquakes and bombings. Personnel in fortifications or armored vehicles are protected from thermal and blast wind effects but may be subjected to overpressures as blast waves enter structures and are reflected and reinforced.

Blast casualties will require evaluation for acute trauma in accordance with advanced trauma life support. Response to therapy will be complicated by immune system compromise and delayed wound healing due to any concomitant irradiation.

Military personnel also may experience motor and cognitive performance decrement, retinal burns, flash dazzle, and loss of night vision.

- **Pneumothorax and pneumoperitoneum:** Treat by appropriate surgical intervention. Delayed sequelae such as pulmonary failure may result from severe barotrauma. In the presence of traumatic injury, hypotension must be considered to be due to hypovolemia and not to concomitant head or radiological injury.
- **Spinal injuries:** Treat with immobilization.
- **Suspected fractures:** Splint.
- **Open wounds:** Debride thoroughly and remove all contaminants, including radioactive debris.
- **Tympanic membrane rupture:** Delay treatment if necessary.

Wounds and Radiation

A wound that is left open and allowed to heal by secondary intention can serve as a potentially fatal focus of infection in a radiation-injured patient. Wound healing is markedly compromised within hours of radiation injury.

If at all possible, wounds should be closed primarily as soon as possible. Extensive debridement of wounds may be necessary to allow primary closure. Traditionally, combat wounds are not closed primarily due to the high level of contamination, devitalized tissue, and subsequent morbidity and mortality of the closed-space contamination, but survival of a radiation/combined injury patient will require aggressive therapy.

A decision to amputate an extremity that in ordinary circumstances would be salvageable will rest with the surgeon in the first 2 days following a combined injury. No studies are available regarding the use of aggressive marrow resuscitation.

If surgery cannot be completed at far-forward locations, patients with moderate injury will need early evacuation to a level where surgical facilities are immediately available.

Thermal Injuries

Thermal burns will be the most common injuries. Thermal radiation from a nuclear detonation causes flash burns from absorption of infrared energy and flame burns from fires in the environment.

Since the thermal pulse is direct infrared, exposed skin will absorb the infrared, and the victim will be burned on the side facing the explosion. Any object between personnel and the fireball will provide a measure of protection. Some protection against thermal flash also can be achieved by loose, light-colored clothing, possibly reducing the injury to partial thickness burns.

Close to the fireball, thermal output is so great that everything is incinerated. The actual range out to which overall lethality would be 100% will depend on the yield, position of burst, weather, and environment.

Firestorm and secondary fires will cause typical flame burns, compounded by closed-space fire-associated injuries. Other likely injuries include toxic gas injury from burning plastics and other material, superheated air inhalation burns, steam burns from ruptured pipes, and all other large conflagration injuries.

Clothing made of natural fibers should be worn next to the skin because complications in the treatment of skin burns may arise from melting of synthetic fibers. These burns will not be limited to exposed surfaces.

The respiratory system also may be exposed to the effects of hot gases. Respiratory system burns are associated with severe morbidity and high mortality rates. Early endotracheal intubation is advisable whenever airway burns are suspected.

Eye Injuries

Sudden exposure to the high-intensity visible light and infrared radiation of a detonation will cause eye injury, specifically to the chorioretinal areas. Individuals looking directly at the flash will receive retinal burns. Eye injury is due not only to infrared energy but also to photochemical reactions that occur in the retina with light wavelengths in the range of 400–500 µm.

Direct optical equipment such as binoculars will increase the likelihood of damage. Night vision apparatus electronically amplifies and reproduces the visual display but does not amplify the infrared or damaging wavelengths and will not cause retinal injury.

Flash blindness occurs with peripheral observation of a brilliant flash of intense light energy, for example, a fireball. This is a temporary condition that results from a depletion of photopigment from the retinal receptors. The duration of flash blindness can last several seconds when the exposure occurs during daylight. The blindness will then be followed by a darkened afterimage that lasts for several minutes. At night, flash blindness can last for up to 30 minutes.

Combined Injury

Combined injury is generally defined as radiation injury plus significant mechanical trauma or burns. Human radiation exposure events such as the Hiroshima and Nagasaki bombings or the Chernobyl accident were combined injury events. Combined injury would also be expected after a radiological or nuclear attack in an urban area. It is generally accepted in scientific circles that all combined injuries carry a worse prognosis than for irradiation alone.

General medical considerations after detonation of a small-yield weapon include not only ARS effects but also thermal burns, blast overpressure effects, cutaneous burns from fallout, possible inhalation of fission products, and delayed effects over years. When combined injury is superimposed in a radiation-injured system, trauma symptoms often mask and exacerbate the first reliable signs of radiation injury.

The synergistic lethality of radiation combined injury is an important consideration. However, mechanisms underlying the high mortality associated with complex radiation injuries are poorly understood.

Thresholds for Weapons Effects

Thermal and pressure effects may be significant. A thermal flux of 2–3 cal/cm^2 is sufficient for a first-degree thermal burn, 4–5 cal/cm^2 for a partial-thickness burn, and 6–8 cal/cm^2 for a full-thickness burn. Tympanic drum rupture in young adults begins at 5 psi overpressure. The threshold for pulmonary edema is approximately 12–15 psi peak overpressure, with damage increasing linearly with overpressure. The LD50 for pressure effects is approximately 50 psi.

For thermal burns, the scaling is linear; e.g., the thermal energy received at a specified distance from a W KT explosion is W times that for a 1 KT burst. As a reference, most paper ignites at approximately 10 cal/cm^2.

Overpressure calculations are slightly more complicated. The range to which a given overpressure extends scales as the cube root of the yield.

Distribution of Injuries

Various mathematical simulations have examined the distribution of injury in a low-yield weapon event. One predicted distribution of injury is as follows. Single Injury (30%) would include radiation injury (R) 5–15%, thermal burns (B) 15–20%, and trauma and wounds (W) 5–10%. Combined injury (70%) is estimated to have R+W+B approximately 20–30%, R+B 30–40% and W+B 5–10%.

Of the documented casualties at Hiroshima, 44% had thermal burns, 57% trauma, and 26% radiation injury. Hospital damage was severe. Of 45 initial hospitals in operation, only three were left standing and able to function to any reasonable degree. Physician and nursing casualties also were severe. The number of physicians registered in Hiroshima prior to the blast was 298; 28 were uninjured and 59 were functional post-event. Of the 1780 nurses registered in the city, 1654 became casualties.

Psychological Support

Proper treatment of the psychological consequences of nuclear events is crucial to the long-term well-being of communities and their members.

Immediate Psychological Response

Radiation elicits fear in both military and civilian populations. Often this fear is considerably out of proportion to the true medical significance of the radiation-related event. Radiation illness symptoms in just a few people can produce devastating psychological effects on an entire community or unit that is uninformed about the physical hazards of radiation. This acute anxiety has the potential to become the dominant source of emotional stress in a unit. Military members may be more likely to focus on radiation detection to the exclusion of other hazards and thus increase the potential of conventional injuries.

Minimizing Combat Stress Effects

The number of combat stress casualties depends on the leadership, cohesiveness, and morale of a unit. Positive combat stress behaviors, such as altruism and loyalty to comrades, will occur more frequently in units with exceptional esprit de corps. Survivor guilt, anticipation of a lingering death, large physical casualty numbers, and delayed evacuation all contribute to acute stress.

Long-Term Psychological Effects

Long-term psychological effects of radiation exposure can manifest years after the causative exposure. Those who have been exposed may experience feelings of vulnerability, post-traumatic stress, chronic anxiety, and loss of control. The patient also may experience fear for the safety of future generations.

Affected individuals appear to fall into one of three groups:

- Distressed
- Behavioral changes
- High risk to develop psychiatric illness

Common reactions may manifest as sadness, anger, fear, difficulty sleeping, impaired ability to concentrate, disbelief, or nonspecific somatic complaints. This condition is often referred to as MIPS, multiple idiopathic physical symptoms.

Outcomes vary widely. Most individuals improve over time, but for a few individuals, the course is less benign. Physicians and psychologists must

remember that people with no prior history are vulnerable to psychiatric illness after a radiation exposure. This also could include crucial emergency response and field medical staff.

Treatment

A well-organized, sustained, effective medical response will instill hope and confidence, reduce fear and anxiety, and support the continuity of basic military and community functions. Casualties should be treated with the primary combat psychology maxims of proximity, immediacy, and expectancy in order to minimize long-term consequences. Treat casualties close to the unit, as early as possible, and communicate expectations that they will return to their units.

Following a radiation event, military personnel likely will turn to trusted healthcare providers or mentors for information and guidance. Healthcare providers therefore will play a key role in determining the long-term care and medical surveillance of soldiers' response to a radiological event. General healthcare providers should be able to care for these patients with proper information about the potential long-term effects of radiation injury and with liberal referral to psychiatric or psychological services.

It is common in health physics radiation dosimetry calculations for some time to elapse before final results are available. During this time period, ensuring consensus among experts can help to allay patient fear and anger.

Psychological Counseling Regarding the Delayed Effects of Radiation Injury

Medical personnel at all levels of care need to be knowledgeable concerning the worry and psychological distress that patients experience regarding delayed effects of radiation exposure.

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Delayed Effects

Delayed effects of radiation include radiation-induced carcinogenesis, genetic issues in offspring, late organ effects (typically vascular changes, fibroatrophy, and thyroid dysfunction), cataracts, and infertility.

Studies on Long-Term Effects of Radiation

The Biological Effects of Ionizing Radiation Committee 7 of the National Academy of Sciences, in its recent report (BEIR VII, 2006), extensively considered the mathematical risk-dose models currently in use. The BEIR VII committee concluded that the best model for the risk of delayed effects is still the linear non-threshold (LNT) model. The LNT model implies that the risk of a given delayed effect goes through zero at zero dose and increases linearly with increasing dose.

The Dosimetry System 2002 (DS02) is the latest dose reconstruction from the Hiroshima and Nagasaki weapon events. A large cohort of radiation survivors have been followed since 1945. Statistically significant evidence is noted for radiation-induced leukemia of all varieties except chronic lymphocytic leukemia (CLL). In addition, radiation-induced carcinoma has been reported for the breast, thyroid, colon, stomach, lung, and ovary. Borderline or inconsistent results are noted for radiation-induced carcinoma of the esophagus, liver, skin, bladder, and central nervous system (CNS) as well as for multiple myeloma and lymphoma.

Cancer Risk

The BEIR VII report is an authoritative source on the risk of low-level radiation-induced cancer. BEIR VII estimates that 43 out of every 100 people in the United States will be diagnosed with cancer. Of these, one cancer out of the 43 could be radiation-related if that individual had received a dose of 100 mSv (10 rem). Risk furthermore is considered linear at lower or higher doses below the threshold for deterministic effects (0.5–0.75 Sv).

American Cancer Society statistics (2001-2003) suggest 1 in 2 males will have cancer in his lifetime and that the rate for women is 1 in 3. An average of these rates is consistent with the 43% incidence suggested by BEIR VII.

Clinical Example: Long-Term Cancer Risk

Event. Estimate the extra cancer risk for a young man acutely exposed to 0.1-Gy (10-rad) whole-body Cs-137 gamma radiation.

Solution. BEIR VII estimates that approximately one cancer per 100 people (1%) could result from a single exposure to 0.1 Sv (~ 10%/Sv). This patient would have a natural probability of ~ 50% of eventually getting cancer. With a 0.1-Gy dose, the extra risk of getting cancer in his lifetime is therefore ~ 1%, for a total of ~ 51%. The reader should note that risk estimates among various Federal agencies, advisory groups, and international committees vary a bit (BEIR VII, IAEA, NCRP, EPA, etc.), but all are generally in the above range.

As a working number, physicians generally consider the extra risk of **fatal** radiation-induced cancer to be ~ 5%/Sv above background values. This is often helpful in patient counseling.

Non-Cancer Effects

Radiation also causes late effects other than cancer. These include cataracts (particularly of the posterior pole of the lens), hyperparathyroidism, and a decrease both in T-cell mediated immunity and in the B-cell humoral response. Survivors of in utero exposure have also experienced infant microcephaly, mental retardation, growth and development delay, lower IQ, and poor school performance.

Radiation-induced cataracts are well documented, most notably seen in the posterior pole of the lens. Neutrons are particularly effective in cataract formation.

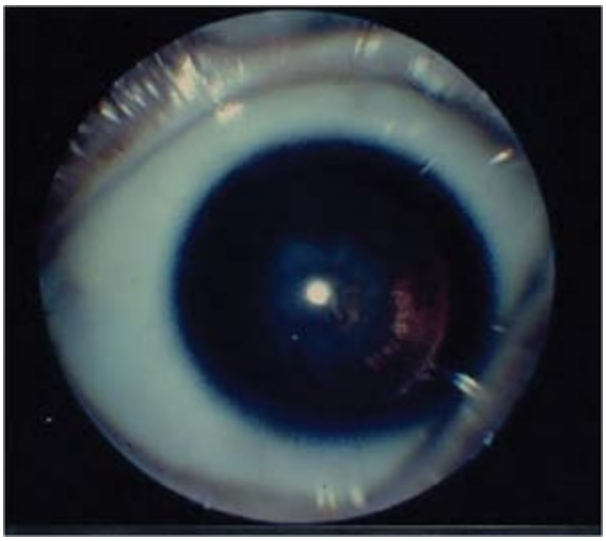

Figure 16. Cataract from 21-year-old woman 805 m from hypocenter at Nagasaki. ▲

The threshold dose for cataract formation (Figure 16) is approximately 2 Gy (greater with fractionated doses). At a 40-Gy dose to the eye, approximately 100% will form cataracts. The latency period ranges from 2 months to 35 years. In general, with increased dose to the eye, the latency period decreases.

Radiation and Pregnancy

Pregnant patients almost always are worried about possible fetal effects from radiation exposure. However, no statistically significant effects have been noted for medically significant irradiation before conception. If irradiation occurs during transit of the blastocyst down the fallopian tube, an “all or none” effect is generally noted. If uterine implantation is successful, the pregnancy generally has a successful outcome.

According to new data from Hall and Giaccia in Radiobiology for the Radiologist, 6th edition (2006), during the gestational period from day 10 to week 25, a dose of 10 cGy (10 rad) is considered the cutoff point at which a pregnancy termination might be considered, based on medical issues relevant to the mother, the wishes of the couple, the possibility of CNS damage and intellectual disability of the child, religious background of the parents, and many other factors. This will help to put into perspective the magnitude of dose that physicians and their patients should discuss during pregnancy.

For a uterine dose > 0.5 Gy, growth retardation, gross congenital malformations, and microcephaly have been the predominant effects noted. Interestingly, there has been no report of external irradiation inducing morphologic malformation in a fetus unless it also exhibits growth retardation or a CNS anomaly. The highest risk of mental retardation is irradiation of the fetus during the period of major neuronal migration (8–15 weeks). At a 1-Gy fetal dose, approximately 75% will experience mental retardation.

Exposure to high levels of radiation is also clearly a risk factor for childhood leukemia. Japanese adult atomic bomb survivors had a 20-fold increased risk of developing acute leukemia (except CLL) usually within 6–8 years after exposure. Studies on in utero exposure and childhood exposure to low levels of radiation show mixed results.

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Decontamination Techniques

Safety of Healthcare Personnel

Radiologically contaminated patients generally pose no danger to healthcare personnel. It is virtually impossible for a living patient to be so contaminated as to pose a threat to healthcare providers. The hazard from a radiologically contaminated casualty will be negligible, both to attending medical personnel and the facility, so necessary medical or surgical treatment must not be delayed because of possible contamination. Unlike chemical contaminants, radiological material active enough to be an immediate threat can be detected from several meters away.

Initial Management

The initial management of a casualty contaminated by radiological agents is to perform all immediate life-limb-saving actions without regard to contamination. All casualties entering a medical unit after a radiological attack should be considered contaminated unless certified as noncontaminated. Radiological decontamination, that is, the removal of radioactive particles from surfaces, demands a significant contribution of resources and can take substantial time. Decontamination should never interfere with medical care and contaminated casualties should not be barred entry from a medical facility if entry is necessary for life-saving care.

Decontamination Techniques

Radiological decontamination is performed in an identical manner to doctrinal chemical decontamination. The main difference is in timing. Chemical decontamination is an emergency. Radiological decontamination is not. Personal decontamination is decontamination of self.

Casualty decontamination refers to the decontamination of casualties. Personnel decontamination usually refers to decontamination of noncasualties. Mechanical decontamination involves measures to remove radioactive particulates, for example, by filtering drinking water.

Removal of outer clothing and shoes and rapid washing of exposed skin and hair removes ~ 90% of contamination. The 0.5% hypochlorite solution used for chemicals also will remove radiological contaminants, but plain soap is often more available and is preferred. Take care to avoid irritating the skin. Some radionuclides can be absorbed directly through the skin, and the likelihood is increased if the skin becomes erythematous. Surgical irrigation solutions should be used in liberal amounts in wounds, the abdomen, and the chest. All such

solutions should be removed by suction, if feasible, instead of sponging and wiping.

If practical, the effluent should be sequestered and disposed of appropriately. Normal hospital barrier clothing is adequate to prevent contamination of medical personnel. Only copious amounts of water, normal saline, or eye solutions are recommended for the eye. Also see the topic Wound Contamination.

Radiation detectors can locate external radioactive material. The most common contaminants will emit primarily alpha and beta radiation. Gamma-radiation emitters may cause whole-body irradiation. Beta emitters when left on the skin will cause significant burns and scarring. This can be prevented by washing off the contaminants. Alpha radiation does not penetrate the epithelium. External contamination of the skin and hair is particulate matter that can be washed off.

Decontamination is usually performed by the emergency service and, ideally, prior to arrival at medical facilities. As this will not always be possible, decontamination procedures should be part of the operational plans and guides of all divisions and departments to ensure flexible response and action and to prevent delay in needed medical treatment.

Routine patient decontamination is performed under the supervision of medical personnel. Moist cotton swabs of the nasal mucosa from both sides of the nose should be obtained, labeled, and sealed in separate bags. These swabs can be examined for evidence of radioactive particle inhalation. Significant decontamination will occur in the normal emergency evaluation of patients by careful removal and bagging of clothing.

Removal of MOPP and other exterior garments during the course of resuscitation will remove nearly all contamination except where the suit has been breached. During initial decontamination in the receiving areas, bandages are removed and the wounds are flushed. The bandages are replaced only if bleeding recurs. Unlike chemical agents, radioactive particles will not cause acute injury, and decontamination sufficient to remove chemical agents is more than sufficient to remove radiological contamination.

Careful examination of the body with certified radiacs such as the AN/VDR–2 and the AN/PDR–77 will confirm adequate decontamination. Particular attention must be paid to the hands, fingers, face, hair, and feet. For alpha emitters, a count of < 1000 disintegrations/minute and for beta radiation < 1 mR/h (10 µSv/h) is clean. Gamma radiation may be detectable at up to twice the local background levels in the decontaminated individual.

Radiological particulate transfer can be resolved by a second deliberate decontamination at the medical treatment facility. This will help prevent the spread of contamination to areas of the body previously uncontaminated, contamination of personnel assisting the patient, and contamination of the medical facility. In most cases of contamination of equipment and buildings, a mixture of normal housecleaning methods will remove the material. Vacuum cleaners that can handle wet material and have high-efficiency filters are particularly useful. Some surfaces may require repeated scrubbing and vacuuming before they are free of contamination.

Wound Contamination

Local wound contamination by particulate matter should be removed if possible. Alpha and beta emitters left in the wound will cause extensive local radiation damage and may be absorbed into the systemic circulation and redistributed as internal contaminants. If possible, a glove-covered radiac probe should be placed carefully into the dried wound, without touching any of the wound surfaces.

Do not contaminate the probe with radioactive particles, body fluids, or talcum powder! Tissue fluids or protective gloves may prevent the detection of alpha and weak beta particles. After determining that adequate decontamination has been obtained, the wound should again be thoroughly irrigated with saline or other physiologic solution. Aggressive surgery such as amputation or extensive exploration should not be undertaken to “eliminate radioactive contamination.” The surgical damage will far exceed any potential decrease in lifetime radiological exposure risk.

Decontamination of Partial-Thickness Burns

Partial-thickness burns should be thoroughly irrigated and cleaned with mild solutions to minimize irritation of the burned skin. Blisters should be left closed; open blisters should be irrigated and treated in accordance with appropriate burn protocols. In full-thickness burns, radioactive contaminants will slough in the eschar. As there is no circulation in the burned tissue, contaminants will remain in the layers of dead tissue.

The presence of radiological contamination can be confirmed readily by passing a radiation detector (radiac) over the entire body. Open wounds should be covered prior to decontamination. Contaminated clothing should be removed carefully, placed in marked plastic bags, and removed to a secure location within a contaminated area. Bare skin and hair should be thoroughly washed; if practical, the effluent should be sequestered and disposed of appropriately. Excision of wounds is appropriate when surgically reasonable. Radioactive contaminants in the wound surfaces will be removed with the tissue.

Command Guidance

Medical Guidance for Commanders

Line commanders will require practical advice from their medical officers concerning radiation effects on their personnel. Radiation effects must not be minimized or exaggerated. Risks must be considered relative to other combat hazards. For acute doses < 1.25 Gy, medical guidance to the commander should be based on long-term effects, primarily increased lifetime cancer risk, of exposure to radiation above normal occupational levels.

The previous Allied Command Europe (ACE) Directive 80-63 defines measures to be taken against the health hazards of low-level radiation. Such health hazards should not significantly affect the operation per se but would contribute to the risk of developing long-term health problems. With exposures < 1.25 Gy, the overall effectiveness of combat units will not be degraded. Above this threshold, tactical commanders must be advised of their forces' diminished capability to fight.

Newer references have commented on the principles in ACE Directive 80-63. These guidelines technically apply only to units under ACE. NATO STANAG 2473 is a commander's guide to radiation exposures in non-article 5 crisis response operations. Joint Publication 3-11 (26 August 2008) considers operations in chemical, biological, radiological, and nuclear (CBRN) environments. Both documents are available on the Internet.

Effects on Individual and Unit Performance

The phrase "combat effective" is used for personnel suffering radiation sickness signs and symptoms to a limited degree but who will be able to maintain at least 75% of their pre-exposure performance level. Individuals identified as "performance degraded" would be operating at 25%–75% of their pre-exposure performance level. Those identified as "combat ineffective" should be considered capable of performing their tasks at 25% (at best) of their pre-exposure performance level.

The radiation exposure status (RES) of a given unit is based on the operational exposure above normal background radiation. It is designed to be an average, based upon unit-level dosimeters, and is not useful for the individual casualty.

Medical officers may adjust a unit's RES after careful evaluation of the exact exposure status of individual members of the unit. When possible, both physical and biological dosimetry should be used. The unit status should reflect the arithmetic mode of the available radiation exposure history of all individual members. Any unit member whose exposure status is more than one full category (or subcategory in operations other than war) greater than the mode should be replaced. A command health physicist should be consulted whenever possible.

When the dose rate is known to be less than 50 mGy per day, dosimetry should be available to allow the RES category to be reduced after 3 months at normal background levels.

When individual dosimetry is unavailable, a period of 6 months since the last radiation exposure above background is sufficient to upgrade a unit's RES status one category (or subcategory) one time only. Table 8 shows the effects of exposures from RES 0 through 1E.

Appendices

Table 8. Radiation Injuries and Effects of Radiation Exposure of Personnel. ▲

RES	Long-term health effects	Medical note	Medical actions
0 (‹ 0.05 cGy)	Normal risk	U.S. baseline 20% lifetime risk of fatal cancer.	Record in Exposure Record of normally monitored personnel.
1A (0.05–0.5 cGy)	Up to 0.04% increased risk of lifetime fatal cancer	None (0.001 Sv annual general population exposure limit).	Record as history in Medical Record: tactical operation exposure.
1B (0.5–5 cGy)	Occupational risk 0.04–0.4% increased risk of lifetime cancer	Reassurance (0.05 Sv U.S. annual occupational limit).	Record in Medical Record: tactical operation exposure.
1C (5–10 cGy)	0.4–0.8% increased risk of lifetime fatal cancer	Counsel regarding increased long-term risk. No live virus vaccines x 3 months.	Record in Medical Record: tactical operation exposure.
1D (10–25 cGy)	0.8–2% increased risk of lifetime fatal cancer	Potential for increased morbidity of other injuries or incidental disease. ‹ 2% increased lifetime risk of fatal cancer.	Record in Medical Record: tactical operation exposure. Consider routine evacuation from theater IAW commander's operational guidance.
1E (25–70 cGy)	2–6% increased risk of lifetime fatal cancer	Increased morbidity of other injuries or incidental disease. ‹ 6% increased lifetime risk of fatal cancer.	Record in Medical Record: tactical operation exposure. Consider expedited evacuation from theater per commander's operational guidance.

Table 9. International System of Units—Conversions. ▲

Old unit curie (Ci)	**SI unit** becquerel (Bq)	**Old unit** rem	**SI unit** sievert (Sv)
1 pCi	37 mBq	0.1 mrem	1 µSv
27 pCi	1 Bq	1 mrem	0.01 mSv
1 µCi	37 kBq	1 mrem	10 mSv
27 µCi	1 MBq	100 mrem	1 mSv
1 Ci	37 GBq	500 mrem	5 mSv
27 Ci	1 TBq	1 rem	10 mSv
		1 rem	1 cSv
		100 rem	1 Sv
rad	gray (Gy)		
1 rad	1 cGy		
100 rad	1 Gy		
1 rad	10 mGy		

Table 10. Acronyms and Abbreviations. ▲

AFRRI	Armed Forces Radiobiology Research Institute
ANC	absolute neutrophil count
ARS	acute radiation syndrome
BAT	Biodosimetry Assessment Tool
CBC	complete blood count
CLL	chronic lymphocytic leukemia
CRP	C-reactive protein
CSF	colony-stimulating factor
DTPA	diethylenetriaminepentaacetic acid
DU	depluted uranium
EDTA	ethylenediaminetetraacetate
ETI	early transient incapacitation
FDA	Food and Drug Administration
G-CSF	granulocyte colony-stimulating factor
GI	gastrointestinal
G-M	Geiger-Mueller
GM-CSF	granulocyte-macrophage colony-stimulating factor
Gy	gray
IND	improvised nuclear device
KI	potassium iodide
LD	lethal dose
MOPP	mission-oriented protective posture
qd	every day
QF	quality factor
rad	radiation absorbed dose
RDD	radiation dispersal device
rem	radiation equivalent in man
RES	radiation exposure status
SC	subcutaneous
Sv	sievert
WBC	white blood count

▲