

Arizona Department of Health Services Radiological Emergency Response Plan



**Division of Public Health Services
Bureau of Emergency Preparedness and Response**

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FORWARD

The Radiological Response Plan provides guidance for healthcare and public health professionals (PHP) responding to a radiological event. Healthcare and PHP responders should never assume there is only one agent present at the scene, unless evidence is presented through scientifically correct and appropriate sampling results. Portions of this plan may not apply if there are chemical or biological agents present. The chemical biological hazard to the worker may be significantly higher than the radiation hazard and the chemical biological response requirements shall take precedence over radiation precautions.

I. INTRODUCTION

RADIATION AND LIFE

Radiation is energy traveling through space. Sunshine is one of the most familiar forms of radiation. It delivers light, heat and suntans. We control its effect on us with sunglasses, shade, air conditioners, hats, clothes and sunscreen.

There would be no life on earth without lots of sunlight, but we have increasingly recognized that too much of it on our persons is not a good thing. In fact it may be dangerous, so we control our exposure to it.¹

Sunshine consists of radiation in a range of wavelengths from long-wave infrared to short-wavelength ultraviolet, which creates the hazard.

Beyond ultraviolet are higher energy kinds of radiation which are used in medicine and which we all get in low doses from space, from the air, and from the earth. Collectively we can refer to these kinds of radiation as ionizing radiation. It can cause damage to matter, particularly living tissue. At high levels it is therefore dangerous, so it is necessary to control our exposure. All organisms are continuously exposed to radiation from either natural or synthetic sources.¹

Living things have evolved in an environment which has significant levels of ionizing radiation. Furthermore, many of us owe our lives and health to such radiation produced artificially. Medical and dental X-rays discern hidden problems. Radiation is used to diagnose ailments, and some people are treated with radiation to cure disease. We all benefit from a multitude of products and services made possible by the careful use of radiation.¹

Background radiation is that which is naturally and inevitably present in our environment. Levels of this can vary greatly. People living in granite areas or on mineralized sands receive more terrestrial radiation than others, while people living or working at high altitudes receive more cosmic radiation. A lot of our natural exposure is due to radon, a gas which seeps from the earth's crust and is present in the air we breathe.¹

In the United States, the average dose of radiation an individual receives per year is estimated to be 3.6 milliSieverts (mSv), 80% of which is from natural sources and 20% of which is from man-made sources. The full effects of low-dose natural radiation are not known, but high doses have been shown to be carcinogenic. At very high-dose exposures over a short period of time, immediate and lethal health effects can occur.^F

IONIZING RADIATION

Generally, the toxicity caused by ionizing radiation is directly related to the quantity of energy deposited into the living organism and the subsequent disruption of metabolic and reproductive pathways. Low-level exposure from accidental contact with radioactive isotopes in laboratory research may lead to

relatively minor toxicity. Alternatively, acute sickness and even death may occur after the inappropriate handling of high-level radioactive material such as cobalt-60 from radiographic or radiotherapy machinery. In a terrorism context, a radiation dispersal device (RDD), “dirty bomb,” could result in conventional blast and thermal injuries. If these devices are laced with significant amounts of radioactive material, the additional risk of radiation exposure would exist for both bomb victims and rescue workers. Detonation of nuclear weapons or improvised nuclear devices would lead to catastrophic blast and thermal injuries in addition to far-reaching lethal radiation consequences.²

Currently, relatively few medical treatments are available to counter radiological and nuclear threats, and most of those in development will need extensive preclinical testing before they can be evaluated for licensure. Radiological and nuclear threats to the nation are complex, encompassing the detonation of conventional explosives combined with radioactive materials (“dirty bombs”), placement of radioactive sources in public locations, contamination of food and water supplies, attacks on nuclear reactors or sites where radioactive materials are stored, or, in a worst case scenario, the detonation of a nuclear explosive device. Notably, only a small number of radiation countermeasures have been entered into the Strategic National Stockpile (SNS). More such agents are needed, based on the range of options (there really aren’t THAT many that can be taken seriously) that could be employed by terrorists, the need for urgent intervention following radiation exposure, and the medical complexities of acute and chronic ionizing radiation injury.³

Ionizing radiation cannot normally be seen by the human eye, nor can it be smelled, heard, or otherwise detected by our normal senses. Radiation can only be detected by radiation detection instruments. This characteristic makes radiological emergencies different from other types of emergencies such as floods, hurricanes or explosions.⁴

Radioactive decay is the process in which unstable atomic nuclei assume a more stable configuration by emitting particles with kinetic energy (alpha or beta particles) or electromagnetic waves (gamma rays). If a person is exposed to these high-energy particles or electromagnetic waves, energy is deposited into the tissues and can cause injury.⁴

Radiation accidents can arise from problems with nuclear reactors, industrial sources and medical sources. The existence of these accident potentials has been present for many years. Our society has developed safeguards to significantly reduce the likelihood of an accident to very low levels. Events of the past few years highlighted by the World Trade Center catastrophe place another risk on the table. That new risk is the intentional non-accidental radiation catastrophe produced by an act of terrorism. Although there are some differences between various types of incident sources, there are elements common to all of them.⁵

II. RADIATION

IONIZING VERSUS NONIONIZING RADIATION

Radiation can be broken down into 2 categories: *ionizing radiation* and *nonionizing radiation*. The term ionizing radiation refers to either high-energy particles or electromagnetic waves that have the ability to deposit enough energy to break chemical bonds and produce an ion pair. Ionization occurs when the process of energy transfer liberates an orbital electron from an atom or molecule producing this ion pair. If living cells receive this energy, cellular function becomes compromised by DNA damage and mutation.²

Nonionizing radiation refers to radiation that lacks the energy to liberate orbital electrons. All radiation from the electromagnetic spectrum except x-rays and gamma rays are included in this category. Examples of nonionizing radiation include microwaves, visible light, and infrared light. Because nonionizing radiation is lower energy radiation, injury is usually related to local heat production and is generally less severe. Ionizing radiation is consequently the focus of radiation-induced injury.²

IONIZING RADIATION TYPES

Gamma Radiation (γ): Gamma radiation, emitted during the nuclear detonation or later in fallout, is highly energetic and is so penetrating that a significant part will pass through the human body without interaction. About 75% of the photons will interact with and lose energy to the atoms of the target tissue. This energy deposition may occur anywhere along a given photon's path, and therefore, anywhere in the body. If the gamma photon flux is high and the whole body is exposed, a fairly homogeneous deposition of energy will occur. This is in marked contrast to the highly localized energy deposition patterns of alpha and beta radiations. High-energy gamma emitters deposited within the body can result in total body irradiation just as effectively as external sources, if the quantities deposited are large enough and despite the fact that the emitters may not be distributed uniformly throughout the body.^{6,7}

Energy can travel through space in the form of electromagnetic radiation. Electromagnetic radiation is composed of massless waves of oscillating electric and magnetic fields. In a vacuum, these waves move at a constant speed, the speed of light (3×10^8 m/s). All electromagnetic waves propagate with characteristic wavelength and frequency, with the wave's energy being directly proportional to frequency and inversely proportional to wavelength. Within the electromagnetic spectrum, only x-rays and gamma rays have enough energy to produce ion pairs. The remaining waves within the spectrum, such as microwaves and radiowaves, are nonionizing.^{6,7}

IONIZING RADIATION: PARTICULATE RADIATION (IN ORDER OF HAZARD)

Ionizing radiation can also be in the form of particulate radiation, which includes small charged or neutral particles traveling with high energy. These particles may be alpha particles, electrons (beta particles), neutrons, or protons.⁸

Neutron Radiation (n): A neutron is an electrically neutral particle found within the nucleus of an atom. Neutrons are slightly greater in mass than protons. High-energy neutrons rarely occur naturally but can be produced in a particle accelerator or in nuclear reactor as part of the fission process. Neutron exposure is most consequential in a nuclear reactor criticality accident or during nuclear weapons detonation.^{6,7}

Since neutrons are uncharged particles and can react only with the nuclei of target atoms, the probability of interaction of neutrons in the energy range characteristic of the fission spectrum detonation during their path through the human body is roughly comparable to that of low-energy gamma photons. Neutron radiation can result in whole-body irradiation. The energy deposition will not be uniform, and the side of the body which faces the detonation will absorb more energy than the opposite side. The major effect of this non-uniform deposition of energy will be to cause a wide variation in the typical radiation doses causing radiation sickness rather than significant variation in the overall clinical effects.^{6,7}

Beta Particles (β): Beta particles are another type of particulate radiation. These particles are high-energy electrons emitted from decaying isotopes such as strontium-90. Beta particles have a rest mass about 8000 times smaller than an alpha particle and travel at speeds near the speed of light. As a result of these properties, beta particles travel approximately 6 to 12 feet in air. The biological damage from beta particles is less than from alpha particles because the tissue damage is less concentrated.⁸

These high-energy electrons are also easily produced in linear accelerators and are commonly used to generate x-rays and in cancer radiotherapy. As in alpha radiation, the main hazard with beta particles lies with internal exposures. With significant skin exposure, however, beta particles have sufficient energy to cause cutaneous burns, "beta burns."⁹

High speed electrons in the form of beta radiation lose most of their energy after penetrating only a few millimeters of tissue. If the beta emitting material is on the surface of the skin, the resulting beta irradiation causes damage to the basal stratum of the skin. The lesion is similar to a superficial thermal burn. However, if the beta material is incorporated internally, the beta radiation can cause much more significant damage. The damage will be in spheres of tissue around each fragment or source of radioactive material. The total damage is a function of the number of sources and their distribution in

the body. The distribution is determined by the chemical nature of the material.^{6,7,10}

Alpha Particles (α): Alpha particles are charged particles made up of 2 protons and 2 neutrons with zero electrons—essentially the nucleus of a helium atom. In air, alpha particles only travel a distance of up to eight inches, and are unable to penetrate any solid substance to a significant depth. In the body, however, alpha particles can cause significant damage to soft internal tissue because they deposit all their energy in a very short distance.^H These particles are emitted from radioactive nuclei of uranium and radium. Because of their large mass and positive charge, alpha particles are highly effective in transferring energy to tissue but are also easily blocked by a piece of paper or clothing. These particles are only a concern when alpha-emitting isotopes are ingested or inhaled.^{6,7}

The energy of these relatively heavy, positively charged particles is fully absorbed within the first 20 micrometers of an exposed tissue mass. If the source of the radiation is external, all of the alpha radiation is absorbed in the superficial layers of dead cells within the stratum corneum. If anything, even tissue paper, or water, is interposed, the alpha particles will be absorbed, and not reach the skin. Because of this, alpha radiation is not an external hazard.^{6,7}

If alpha emitting material is internally deposited, all the radiation energy will be absorbed in a very small volume of tissue immediately surrounding each particle. Alpha radiation has such limited penetrating ability that the maximum range for the highest energy alpha particle in tissue is less than 100 micrometers. Beyond a radius of about 20 micrometers, the deposition of energy is very small. Due to the high radiation doses within this critical radius, the cells immediately adjacent to the source are killed. Internal deposition of alpha particles are of importance on a long term basis in terms of causing radiation injury which is of greater significance than from beta particles. It should be noted, however, many alpha emitting materials also emit gamma radiation, and this gamma radiation may cause significant tissue injury, even though the total alpha energy exceeds the total gamma energy and the ratio of gamma emissions per alpha is very small. This follows from the fact that the penetrating power of gamma radiation is many times greater than that for alpha radiation so that the total volume of tissue exposed to damaging radiation is many times greater.^{6,7}

A well-recognized source of alpha radiation involves the decay of radium into radon gas. Radium is an alkaline earth metal and a decay product of uranium and is found in uranium-bearing rocks or ores. Radium decays into radon gas, which can accumulate in poorly ventilated areas such as basements. Inhalation of radon on dust particles can lead to substantial doses of alpha

radiation to the bronchi or lungs. The US Environmental Protection Agency attributes 10,000-20,000 cases of lung cancer per year to radon exposure.

Protons (p): A proton is a positively charged particle that is more than 1800 times the size of an electron. Protons make up a major component of cosmic radiation originating from the sun. All but a small amount of the sun's proton radiation is deflected by the earth's magnetic field.^{6,7}

FUNDAMENTAL PROPERTIES OF RADIATION

Table II-1. Fundamental properties of radiation^{6,7}

Properties	Alpha (α)	Beta (β)	Gamma (X-Ray) (γ)	Neutron (n)
Mass	Large mass 2 protons and 2 neutrons (4 amu)(helium nucleus)	Solid mass (about 1/1838 of 1 amu)	No mass electromagnetic wave or photon	Mass of 1 amu
Electrical Charge	+ 2 positive	-1 negative	None	None
Range in the air	Short range ¼ to 2 inches	up to about 10 feet	Very far several hundred feet. Very high penetrating power since it has no mass or charge	Very far. Several hundred feet. High penetrating power due to lack of charge (difficult to stop)
Shielding	2 inches of air, A sheet of paper, dead layer of skin	Plastic, aluminum foil, clothing safety glasses	Inches of Lead, Concrete, Water, Steel	Materials with high hydrogen content, water, concrete, plastic, polyethylene, boron cadmium
External Hazard	Does not represent external hazard.	Externally for unprotected skin and eyes.	Whole body exposure. Can penetrate through the body.	Whole body exposure. Can penetrate through the body.
Biological Hazard	Internal hazard if the source is inside the body (inhaled, ingested, or injected in wound.) Can deposit large amounts of energy in a small area internally	Internal hazard if the source is inside the body (inhaled, ingested, or injected in wound.) Can deposit large amounts of energy in a small area internally	Hazard may be internal or external. This depends on whether the source is outside or inside the body.	Hazard may be internal or external. This depends on whether the source is outside or inside the body.
Sources	Usually emitted by transuranic elements: Uranium, Plutonium, Americium, Radon and Radium	Fissionable products such as Cesium 137, Tritium, Carbon-14, and iodine 132	Fission Products. Many natural emitters in soil, industrial and medical sources. Cesium 137, Cobalt 60, depleted Uranium	Few natural sources. Fission and nuclear reactors. Cosmic radiation entering atmosphere creates neutrons. Plutonium, Californium 252.

SPECIFIC RADIOACTIVE MATERIALS (MOST COMMON)

Americium Americium-241 (^{241}Am) is an alpha emitter, related to plutonium, that is detectable with a standard Radiac meter because of its 60-kEv gamma ray emissions. This material can be found in nuclear fallout and smoke detectors. Americium is generally a heavy metal poison; however, in large quantities, whole-body irradiation can occur. Absorption occurs through skin wounds and pulmonary ingestion. Absorbed americium is eliminated by the renal and hepatic systems.⁷

Cesium Cesium-137 (^{137}Cs) is found in medical radiotherapy devices and was used in the Chechen radiological dispersal devices (RDD) threat against Moscow that was responsible for the worst radiation accident in the Western Hemisphere. Cesium emits both gamma rays and beta radiation. Primary toxicity is whole-body irradiation, and death from acute radiation syndrome has occurred. The material is fully absorbed by the lung, GI tract, and open skin wounds. Cesium is excreted by the renal system. If medical attention is sought early after ingestion, lavage and purgatives may attenuate the severity of future symptoms and improve overall prognosis.⁷

Cobalt Cobalt-60 (^{60}Co) used in medical radiotherapy devices and commercial food irradiators generates high-energy gamma rays and 0.31-MeV beta rays that are detectable with a gamma detector. Cobalt is absorbed primarily by the lungs; less than 5% is absorbed by the GI tract. Primary toxicity is from whole-body irradiation.⁷

Depleted Uranium Depleted uranium is used in specialized munitions, armor, and aircrafts. It emits alpha, beta, and gamma rays that are detectable with a Geiger-Mueller (G-M) counter. However, radiation effects from depleted uranium have been negligible in Department of Defense longitudinal studies. The primary danger from depleted uranium is heavy metal toxicity, but even this toxicity has occurred only rarely in military personnel subjected to shrapnel wounds. Inhaled uranium, which may be produced during tank fires, is metabolized and renally excreted. When in the salt form, uranium is readily absorbed. Fragments of uranium in the skin are metabolized slowly and should be removed when practical.⁷

Iodine Radioactive iodine (RAI) is a normal fission product found in reactor fuel rods. It can be released by rupturing the reactor core and its containment vessel. This material emits beta and gamma rays that are toxic to the thyroid gland. Thyroid uptake of iodine leads to concentration of the isotope and local irradiation similar to thyroid ablation therapy.⁷

Phosphorous Phosphorus-32 (^{32}P) is used in laboratories and in hospitals as a tracer. This material is completely absorbed, deposits in rapidly

replicating cells, and has a strong beta ray that can be detected with a beta-gamma detector.⁷

Plutonium Plutonium-239, 238 (239, 238Pu), produced by uranium reactors, is the primary material in nuclear weapons. It is the predominant radioactive contaminant in accidents involving nuclear weapons. Plutonium does not present an external irradiation hazard because the primary form of its radiation is alpha particles. This material is usually contaminated with americium, which is easily detected by x-ray using a thin-walled gamma probe. Primary toxicity occurs via inhalation of 5-micrometer or smaller particles that remain within the lungs and are metabolized, causing local irradiation damage. GI absorption depends on the chemical state of plutonium because the solid metal form is not absorbed. Stool specimens and urine specimens are positive in 1 day and 14 days, respectively.⁷

Radium Radium-226 (226Ra) is not a federally regulated commodity in the United States; it is found in former Soviet Union equipment, such as instrument illumination, industrial applications, and medical equipment. The primary form of radiation is alpha particles; however, the byproducts can emit beta and gamma rays, so the risk of external irradiation hazard exists. Most exposure is by ingestion, with 30% of exposure through absorption. Little is known about wound absorption, but radium follows calcium, so bone deposition does occur. Long-term exposure is associated with leukemia, aplastic anemia, and sarcomas.⁷

Strontium Strontium-90 (90Sr) is a direct fission product of uranium, both of which emit beta and gamma rays. These are known to be external irradiation hazards if present in quantity. Strontium follows calcium and deposits about 50% of the total dose in the bone. This material is readily absorbed by respiratory and GI routes.⁷

Tritium Tritium (hydrogen-3 or 3H) is hydrogen with a nucleus composed of 2 neutrons and 1 proton. It is used in nuclear weapons, specialized gun sights, and muzzle-velocity indicators. It is unlikely to be a hazard, except in a closed space. Tritium is a beta emitter and is not a significant irradiation hazard. Water formed from tritium (HTO) is completely absorbed and equilibrates with body water. Tritium is excreted in urine and shows up in urine samples within hours of exposure. No adverse reports are documented from a single exposure. The half-time of tritium is 10-12 days; however, this time can be cut in half by increasing oral fluid intake.⁷

Uranium Uranium-238, 235, 239 (238, 235, 239U) is found in depleted uranium, natural uranium, fuel rods, and weapons-grade material. Uranium emits alpha, beta, and gamma radiation. Depleted uranium and natural uranium are not serious irradiation threats. Used fuel rods and weapons-grade enriched uranium containing fission products can emit significant levels

of gamma radiation. If enough enriched uranium is brought together, a critical mass may form and emit lethal levels of radiation. This could be observed in fuel reprocessing plants or melted reactor cores. Inhaled uranium compounds may be metabolized and excreted by the renal system. If the levels of uranium within the urine exceed 100 mcg/dL following acute exposure, renal failure may be precipitous. Uranium is absorbed as a salt and not as a metal.⁷

ALLOWABLE LEVELS OF INTAKE (ALI'S) FOR SELECTED RADIONUCLIDES

These are the yearly legal limits for radiation workers, who may experience such intakes *every year*. Internally contaminated individuals with less than one ALI would not ordinarily be candidates for decorporation therapy, as their effective dose is not significant enough to merit concern.^{11, 12}

Table II-2. Allowable Levels of Intake (ALI's) for Selected Radionuclides in μCi .^{6,7}

Radionuclides	Ingestion		Inhalation	
Americium-241	0.8 μCi	8E-1	0.006 μCi	6E-3
Cesium-137	10 μCi	1E+2	200.0 μCi	2E+2
Cobalt-60	W: 500 μCi Y: 200 μCi	5E+2 2E+2	W: 200.0 Y: 30.0 μCi	2E+2 3E+1
Iodine-125	40 μCi	4E+1	60 μCi	6E+1
Iodine-131	30 μCi	3E+1	50 μCi	5E+1
Iridium-192	900 μCi	9E+2	D: 300 μCi W: 400 μCi Y: 200 μCi	3E+2 4E+2 2E+2
Palladium-103	6,000 μCi	6E+3	D: 6,000 μCi W: 4,000 μCi Y: 4,000 μCi	6E+3 4E+3 4E+3
Phosphorus-32	600 μCi	6E+2	D: 900 μCi W: 400 μCi	9E+2 4E+2
Plutonium-239	0.8 μCi	8E-1	W: 0.006 μCi Y: 0.02 μCi	6E-3 2E-2
Radium-226	2 μCi	2E+0	.6 μCi	6E-1
Strontium-90	30 μCi	3E+1	D: 20 μCi Y: 4 μCi	2E+1 4E+0
Tritium (hydrogen-3):	80,000 μCi	8E+4	80,000 μCi	8E+4
Uranium-233	10 μCi	1E+1	D: 1 μCi W: 0.7 μCi Y: 0.04 μCi	1E+0 7E-1 4E-2
Uranium-234	10 μCi	1E+1	D: 1 μCi W: 0.7 μCi Y: 0.04 μCi	1E+0 7E-1 4E-2
Uranium-235	10 μCi	1E+1	D: 1 μCi W: 0.8 μCi Y: 0.04 μCi	1E+0 8E-1 4E-2
Yttrium-90	40 μCi	4E+2	W: 700 μCi Y: 600 μCi	7E+2 6E+2

The ALI limits differ for ingestion and inhalation routes because of biodistribution and kinetic differences leading to different effective radiation doses. One ALI

gives an effective dose of about 5 rem, the annual limit of radiation dose permitted for a radiation worker. Compounds may be represented as D, W, and Y signifying body retention times in Days, Weeks, or Years. If there is no such representation, the ALI is for all compounds.^{11,12}

NOTE: The values in the original table are presented in the computer “E” notation. In this notation a value of 6E-02 represents a value of 6×10^{-2} or 0.06, 6E+2 represents 6×10^2 or 600, and 6E+0 represents 6×10^0 or 6. Table II-2 also has the numerical values converted and presented in a more readable format.³⁴ for further information on ALI’s go to 10 CFR 20.1201 Occupational dose limits for adults, and Appendix B to Part 20.¹²

PHASES

The *early phase* (also referred to as the emergency phase) is the period at the beginning of a nuclear incident when immediate decisions for effective use of protective actions are required and must therefore be based primarily on the status of the incident and the prognosis for worsening conditions.

The *intermediate phase* is the period beginning after the source and releases have been brought under control and reliable environmental measurements are available for use as a basis for decisions on additional protective actions.⁵

The *late phase* (also referred to as the recovery phase) is the period beginning at commencement of recovery action designed to reduce radiation levels in the environment to acceptable levels for unrestricted use and ending when all recovery actions have been completed.⁵

TYPES OF RADIATION-INDUCED INJURY

Regardless of where or how an accident involving radiation happens, three types of radiation-induced injury can occur: external irradiation, contamination with radioactive materials, and incorporation of radioactive material into body cells, tissues, or organs.¹³

External Irradiation *External irradiation* occurs when all or part of the body is exposed to penetrating radiation from an external source. During exposure this radiation can be absorbed by the body or it can pass completely through. A similar thing occurs during an ordinary chest x-ray. Following external exposure, an individual is not radioactive and can be treated like any other patient. (Refer to the sections on assessment and treatment in Hospital Emergency Care of the Radiation Accident Patient.)⁵

External irradiation can be divided into *whole-body* exposures or *local* exposures. In either case, the effective dose can be calculated, as discussed below, taking into account the attenuation of the body and the steep gradients of absorbed dose throughout the body.⁵

Contamination The second type of radiation injury involves *contamination* with radioactive materials. Contamination means that radioactive materials in the form of gases, liquids, or solids are released into the environment and contaminate people externally, internally, or both. An external surface of the body, such as the skin, can become contaminated, and if radioactive materials get inside the body through the lungs, gut, or wounds, the contaminant can become deposited internally. Refer to [Managing Emergencies Involving Radiation](#) for additional information.⁵

Incorporation The third type of radiation injury that can occur is *incorporation* of radioactive material. Incorporation refers to the uptake of radioactive materials by body cells, tissues, and target organs such as bone, liver, thyroid, or kidney. In general, radioactive materials are distributed throughout the body based upon their chemical properties. Incorporation cannot occur unless contamination has occurred.⁵

Almost all industrial accidents, most reactor accidents and many medical accidents result in irradiation of the victim. There does not have to be direct contact between the victim and the radiation source, which may be a radiation-producing machine or a radioactive source. Once the person has been removed from the source of radiation, or the machine has been turned off, the irradiation ceases. The victim is not a secondary source of radiation and individuals providing support and treatment are in no danger of receiving radiation from the victim. A person exposed to external irradiation does not become radioactive and poses no hazard to nearby individuals.⁵

These three types of exposures can happen in combination and can be complicated by physical injury or illness. In such a case, serious medical problems always have priority over concerns about radiation, such as radiation monitoring, contamination control, and decontamination.⁵

Deterministic effects: effects that can be related directly to the radiation dose received. The severity increases as the dose increases. A deterministic effect typically has a threshold below which the effect will not occur.¹⁴

Stochastic effect: effect that occurs on a random basis independent of the size of dose. The effect typically has no threshold and is based on probabilities, with the chances of seeing the effect increasing with dose. If it occurs, the severity of a stochastic effect is independent of the dose received. Cancer is a stochastic effect.¹⁴

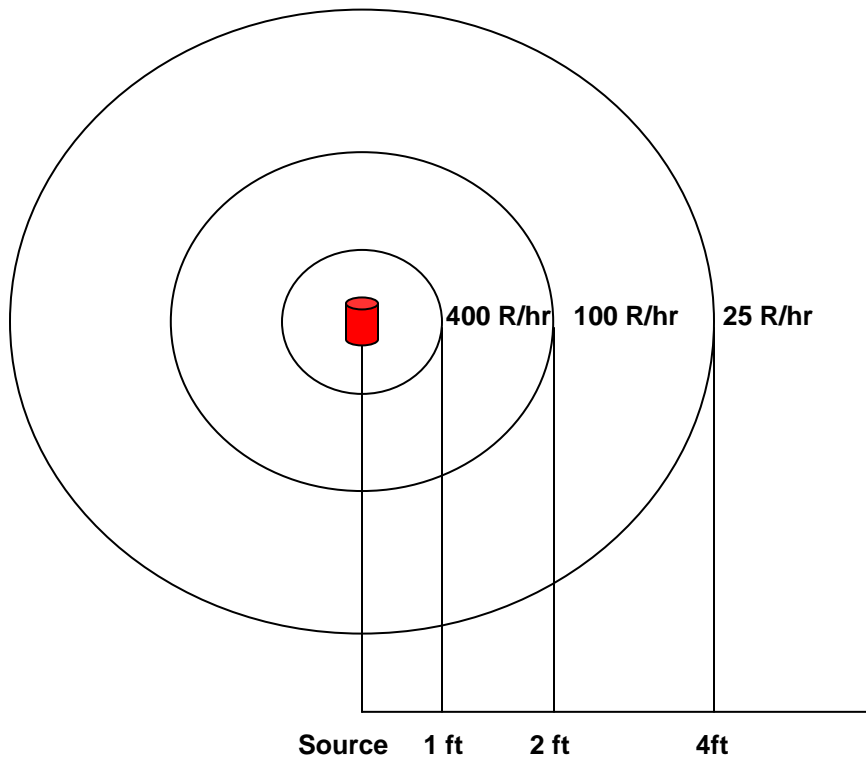
DOSE LIMITS AND EXPOSURE GUIDANCE

ALARA Acronym for "as low as (is) reasonably achievable." Means making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics

of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.¹⁵

The dose limits below, apply to the doses incurred over the duration of the emergency. The dose to workers performing emergency services may be treated as an “once-in-a-lifetime” exposure, and not added to the occupational exposure accumulated under normal, nonemergency conditions for the purpose of determining conformance with the normal occupational limits. (EPA Manual of Protective Action Guides and Protective Actions for Nuclear Incidents (EPA 400 R-92-001)).¹⁵

INVERSE SQUARE LAW



Point source considerations are important because of the dramatic increase in dose that occurs as responders approach the source. the formula used to calculate the change in exposure as the distance from a point source varies is:¹⁵

R₁ is the initial rate
R₂ is the new rate

D₁ is the initial distance
D₂ is the new distance

$R_1 D_1 = R_2 D_2$ therefore $400 \text{ R/hr } (1^2) = R_2 (2^2)$ $400/4 = 100$ as shown above

Double the distance
Halve the distance

1/4 the dose rate
4 times the dose rate.

*Sum of the doses from the external dose and internal dose (from the intake of radioactive material) to nonpregnant, adult emergency workers. Responders performing services during emergencies should limit the dose to the lens of the eye to 3 the listed values and limit the doses to any other organ (including the skin and extremities to 10 times the listed value μ .¹⁵

Table II-3 EPA Guidance for Dose Limits for Workers Performing Emergency Services¹⁵

Dose Limit * (Whole Body)	Emergency Activity Performed	Condition
5 rem	All activities	
10 rem	Protecting valuable property, Hazard control/mitigation	Where lower dose not practicable
25 rem	Lifesaving or protection of large populations	Where lower dose not practicable
More than 25 rem	Lifesaving or protection of large populations	Only on a volunteer basis to persons fully aware of risks involved.

Table II-4. Dose Work Rate Comparisons¹⁵

Dose Rate Recommendations	Actual Values	Exercise Values
Contaminated (Persons)	2 X Background Reading (cpm or μ R/hr or mR/hr)	2 X Background Reading (cpm or μ R/hr or mR/hr)
Hot Line	1 – 5 mR/hr (0.001 – 0.005 R/hr)	100 μ R/hr (0.1 mR/hr)
Work in Hot Zone	1 mR/hr - 10 R/hr (0.001 – 10 R/hr)	100 μ R/hr – 1000 μ R/hr (0.1 mR/hr – 1 mR/hr)
Turn Back Dose Rate (Except Lifesaving)	10 R/hr	1mR/hr
Turn Back Dose Rate (Even for Lifesaving)	200 R/hr	4 mR/hr

1 μ R = 0.001 mR = 0.000001 R

1 R/hr = 1,000 mR/hr = 1,000,000 μ R/hr

Natural Background: Approximately 10 μ R/hr = 0.01 mR/hr = 0.25 mR/day

NOTE: Gamma-ray survey meters usually read values in R/hr (not rem/hr), but the dose limits are given in rem (not R). For gamma radiation, you can consider R/hr and rem/hr to be the same.^v

The green-yellow-red doses correspond to the 5-10-25 rem guidelines from the Dose Guidelines Table. The gray columns represent lethal doses. A 300 to 350 rem dose is considered the LD₅₀ for humans within 60 days without hospital care. A 450 to 500 rem dose is considered the LD₅₀ for humans within 60 days even with hospital care.¹⁵

The Calculation for exposure time is: $\text{Time} = \frac{\text{Dose}}{\text{Dose Rate}}$

If a responder was in a field of 10 R/hr, how long would it take to receive a lethal dose of 500 rem? = 500/10 = 50 hr

Table II-5. Stay Timetable¹⁵

Gamma-ray Dose Rate			Stay Time to Receive This Dose						
Rate/Hr	Rate/min	Rate/sec	1 rem	5 rem	10 rem	25 rem	100 rem	300 rem	400r rem
1 mR/hr	17µR/mn	0.3 µR/mn	6 wk	30 wk	1 year				
5 mR/hr	83 µR/mn	1.4 µR/mn	200 hr	6 wk	12 wk	30 wk	2 yr		
100 mR/hr	1.7 mR/hr	27 µR/mn	10 hr	50 hr	100 hr	250 hr	6 wk	18 wk	30 wk
1R/hr	17mR/hr	270 µR/mn	1 hr	5 hr	10 hr	25 hr	100 hr	300 hr	500 hr
10 R/hr	170 mR/hr	2.7mR/mn	6 mn	30 mn	1 hr	2.5 hr	10 hr	30 hr	50 hr
100 R/hr	1.7 R/mn	27 mR/mn	36 sec	3 mn	6 mn	15 mn	1 hr	3 hr	5 hr
200 R/hr	3.3 R/mn	56 mR/mn	18 sec	90 sec	3 mn	7.5 mn	30 mn	1.5 hr	2.5 hr
500 R/hr	8.3 R/min	140 mR/min	7 sec	36 sec	72 sec	3 mn	12 mn	36 mn	1 hr

PROTECTION

Three Effective Strategies Unsealed radionuclides, sealed sources, X-ray machines, irradiators, and other sources may present a hazard of external exposure. Protection from these sources is based on applying three fundamental strategies (**Time, Distance, Shielding**)^{15, 16}

- *Minimize the time* spent near sources (a linear reduction).
- *Maximize the distance* from sources (an inverse square reduction).
- *Use shielding* of appropriate type (an exponential reduction).

Time Simply reducing the amount of time spent near or in contact with any source results in a proportionate reduction in dose. Minimize the time and you will minimize the dose.^{15,16}

sieverts/hour x hour = sieverts

Distance Exposure decreases with distance according to the *inverse square law*, by which the radiation intensity varies inversely with the square of the distance from a source. Increasing the distance from a source by a factor of two reduces the intensity to one quarter. Increasing the distance from a source by a factor of three reduces the intensity to one ninth.¹⁵

$$1/2^2 = 1/4$$

$$1/3^2 = 1/9$$

This rule has important practical applications. A source with an exposure rate of 100 mR/hr at 10 centimeters from the surface has an exposure rate of 1 mR/hr at 100 centimeters from the surface, or little more than an arm's length away.¹⁵

Remote handling tools may be necessary for sources with high-energy beta particles (such as ³²P), high gamma exposure rates (such as ¹³⁷Cs), or both (such as ²²Na). These can be forceps, tongs, vial racks, trays--in short, anything that will put distance between you and the source. In the laboratory, place stock solutions, equipment, and wastes as far as possible from occupied areas and doorways.¹⁵

Shielding Proper shielding can result in an exponential reduction of dose for gamma emitters and a near-total reduction for beta emitters. Select appropriate shielding materials during the planning stages of any experiment or clinical procedure. Shielding design may be simple--no more complex or costly than sheets of plywood or plastic--or may involve complex calculations that depend on the type of radiation, the energy and frequency of emission, the configurations of source and room, and the occupancy factors.^{G,V}

The amount of shielding required depends on the type of radiation being shielded, the activity of the source, and on the dose rate which is acceptable outside of the shielding material. In choosing a shielding material, the first consideration must be personnel protection. An effective shield will cause a large energy loss in a small penetration distance without emission of more hazardous radiation. However, other factors may also influence the choice of shielding materials such as, cost of the material, weight of the material, and how much space is available for the material. The effectiveness of the shielding material is determined by the interactions between the incident radiation and the atoms of the absorbing medium. The interactions which take place depend mainly upon the type of radiation (alpha, beta, gamma, and neutron), the energy of the radiation, and the atomic number of the absorbing medium.^{8,15}

Shielding for Alpha Particles Alpha particles lose energy rapidly in any medium because of their relatively high ionization loss and are stopped by very thin absorbing materials. A few sheets of paper or thin aluminum foil will absorb alpha particles from alpha-emitting sources. The most energetic alpha will travel only a few tens of mm in air. The outer layer of

skin, approximately 0.07 kg/m² in thickness, will absorb alpha particles up to 7.5 Mega Electron Volts (MeV). Since this is a dead layer of tissue, no harmful effect is produced upon the body. Therefore alpha particles do not present a shielding problem.^{9,15}

Shielding for Beta Particles Beta particles are relatively easy to shield. Since all beta particles have a definite range in matter, one may calculate a thickness of material that will stop them all. Lead is *not* the best material for shielding beta particles. Low density material--wood, plastic, or aluminum--works better. Lead actually may increase the exposure from certain radionuclides. When a beta particle passes close to the nucleus of an atom, its path and velocity may change, giving off excess energy in the form of photons called *bremsstrahlung* radiation. The yield of bremsstrahlung radiation is proportional to the energy of the beta particles and to the atomic number of the shielding material. Lead has a high atomic number, so the amount of beta-particle energy converted to penetrating bremsstrahlung photons may be large. Although only a small fraction of the beta particles may be converted in this fashion, the resulting photons are more penetrating than the beta particles, resulting in unnecessary dose.^{8,9,15}

Plastics make better shields for beta particles because they have low atomic numbers and little beta energy is converted into photons. If necessary--such as with very large or energetic beta sources--shielding may be layered, with the plastic shield nearest the source and a higher-density shield farthest from the source. The higher-density shield absorbs photons produced by beta interaction in the plastic shield.^{9,15}

Table II-6. Percentage of 1 MeV Beta particles absorbed by materials and equipment⁹

Materials and Equipment	% of β Absorbed
Cotton Coveralls	20 %
Plastic Hoods or Goggles	30 %
Cotton or rubber gloves	30 %
Neoprene gloves	50 %
Paper (0.3 mm)	90 %
Safety glasses or respirator	90 %

Shielding for Neutron Radiation Neutron, like gamma rays, are highly penetrating forms of radiation. Neutrons possess no charge and, therefore, are unaffected by the electric fields of absorber atoms. Neutrons are most effectively shielded by materials containing low atomic- number absorbers. Neutrons are slowed to thermal energies by elastic collision and then they are captured by nuclei of the shielding material. Materials commonly used to shield neutrons are concrete, water, and polyethylene.^{9,15}

Shielding for Gamma Rays For gamma emitters and X-rays the ideal absorber, because of its high density, is lead. Its major drawback is a low melting point, which in the case of fire, would leave the source exposed. Other absorbers are concrete, steel, iron, depleted uranium and fansteel. The most commonly used are lead and concrete. When working with lead shielding, it is important that the bench be strong enough to support the weight of the bricks.^{15,16}

RESPIRATORY PROTECTION

PPE protection levels are classified as Level A, Level B, Level C, and Level D. Level A being the greatest protection level with the highest level of respiratory protection, and C the least respiratory protection. For situations where airborne particulates are the chief concern, such as RDD events, Level C protection is generally sufficient.¹⁷

There are several approaches to respiratory protection. Fit-tested full or half face Respirator with P-100 high efficiency particulate air (HEPA) cartridge-filtered respirators should be used when available. Powered-air purifying respirators (PAPRs) with P-100 HEPA cartridges are also useful. Any respiratory protection that is designed to protect responders against chemical or biological agents will likely offer benefits in an RDD event. In fact, concerns for the presence of chemical contaminants at a terrorist event will drive the selection of respiratory protection as they may require a higher level of PPE.¹⁷

SKIN PROTECTION

Current weather conditions, as well as the environment at the event, will drive the selection of anti-contamination clothing. Normal chemical or particulate barrier clothing and gloves give excellent personal protection against airborne particles.^E The choice of clothing will often be driven by other more immediate hazards, such as fire, heat, or chemicals. Protection for these hazards covers any additional threat that radioactive material could pose.¹⁷

Transport of the severely injured to available acute care medical facilities should not be delayed due to suspected or confirmed radiological contamination on the patient. If a critically injured but contaminated patient must be transferred immediately, make preparations for limitation of contamination at the destination facility.¹⁷

SHELTERING

During the “early phase” (Note: It is unlikely that this phase will be applicable to a localized dispersal event like a “dirty bomb.”):¹⁸

- Sheltering will normally be the preferred protective action until an orderly evacuation of the contaminated area can be made. Monitoring for

contamination and applying decontaminating techniques should be performed prior to releasing people.

- Sheltering should be directed if the projected effective dose. Recommendation is, or has the potential to be, greater than 10 mSv (1 rem).
- Sheltering need not be implemented if the projected effective dose is less than 1 mSv (100 mrem).

Evacuation of most population groups should be directed if it is more protective than sheltering, but not if the projected dose is less than 50 mSv (5 rem), with the following exception: For special groups for which evacuation puts them or the public at a greater risk (e.g., persons on medical life support, institutionalized criminals, etc.), evacuation should not be directed if the projected effective dose is less than 100 mSv (10 rem).¹⁸

SOURCES OF LARGE SCALE IONIZING RADIATION RELEASE

Nuclear Power Plants Although construction and operation of nuclear power plants are closely monitored and regulated by the Nuclear Regulatory Commission, accidents, though unlikely, are possible. The most immediate danger from an accident at a nuclear power plant is exposure to high levels of radiation. A nuclear power plant accident would not cause the same widespread destruction as a nuclear weapon. Although radioactive materials could be released in a cloud or plume, no fallout is produced to endanger people. There may be a radiation hazard in the surrounding areas, depending on the type of accident, amount of radiation released, and weather factors. At the onset of an accidental release, radiation would be monitored by authorities to determine potential danger and warn the public. Because it is a known event, local citizens would be evacuated or instructed on how to avoid radiation hazards. Local municipalities train and practice release accident scenarios with a full range of emergency response organizations, and residents are familiar with responses.⁴

To predict radionuclide contamination/emission from a power plant one can look at the previous accidents and releases involved. Among other accidents, one can list the Windscale accident of 1957, the Oak Ridge Pu release of 1959, the explosion of an Army low power reactor in 1961, the 1974 Browns Ferry fire, the Three Mile Island 1979 accident, and the 1986 Chernobyl accidents. Possible accidents are continuously being studied in the industry to assure safety of power plants and compliance with today's regulations.¹³

Table II-7, Release of Radioactive Material From Nuclear Power Plants.^{13,19,20}

Facility	Radioisotopes	Release	Comments
Windscale (now called Sellafield)	¹³¹ I, ¹³⁷ Cs, ⁸⁹ Sr, ⁹⁰ Sr	30,000 Ci, 20,000 of which was from ¹³³ I	There were no acute health effects as result of this accident. However, for 2 weeks, all milk produced on farms within a few kilometers of the plant was collected and withdrawn from consumption due to Sr-90 and radioactive iodine uptake by dairy cattle.
Oak Ridge	¹³³ I	10 Ci of ¹³³ I	The explosion resulted in plutonium contamination of the pilot-plant building, nearby streets, and building surfaces. The adjacent air-cooled graphite reactor building became contaminated when plutonium was drawn into the ventilation system.
U.S. Army Low Power Reactor	²³⁹ Pu, ⁹⁵ Zr, ⁹⁵ Nd	Unknown	Although there were three casualties related with this accident, all of the radioactive material, with the exception of ¹³¹ I, was contained within a three-acre plot.
Three Mile Island	⁸⁵ Kr,	15 Ci	Average dose to people was about 1 millirem. Exposure from a full set of chest x-rays is about 6 millirem. The maximum potential off-site radiation dose was 83 mrem at the site boundary.
Hanford	¹³¹ I, ¹⁰³ Ru, ¹⁰⁶ Ru, ²³⁹ Pu, ⁹⁰ Sr, and ¹⁴⁴ Cs	740,000 Ci	Major radioactive releases occurred between 1944 and 1957. estimations of release in Curies is ¹³¹ I, 739,000; ¹⁰³ Ru, 1,600; ¹⁰⁶ Ru 388; ⁹⁰ Sr, 64.3; ²³⁹ Pu, 1.87; ¹⁴⁴ Ce, 3,770. Epidemiologic studies have not found conclusive evidence of effects in the downwind populations.
Chernobyl	¹³¹ I, ¹³⁷ Cs,	7,300,000 Curies (1,000,000 Ci /24 hours first 7 days)	Caused the deaths, within a few weeks, of 30 power plant employees and firemen responders, 28 with acute radiation syndrome, evacuation of about 116,000 people.

Table II-8. Common radionuclide generators used in nuclear medicine ¹³

Daughter	Mode Half-life	Parent	Half-life
⁶⁸ Ga	68 Minutes	⁶⁸ Ge	²⁷⁵ days
⁸² Rb	1.3 Minutes	⁸² Sr	²⁵ days
^{87m} Sr	2.8 hr	⁸⁷ Y	⁸⁰ hr
^{99m} Tc	6 hr	⁹⁹ Mo	⁶⁶ hr
¹¹³ mIn	100 min	¹¹³ Sn	¹²⁰ days

Radioisotopes are atoms that contain an unstable combination of neutrons and protons. The combination can occur naturally, as in radium-226, or can be produced artificially by altering the atoms, in some cases using a cyclotron and in others, a nuclear reactor. Atoms containing this unstable combination regain stability by shedding radioactive energy, hence the term radioisotope. Nuclear medicine uses small amounts of radiation to provide information about a person's body and the functioning of specific organs. The information received is used by physicians to make an accurate diagnosis of the patient's illness. In certain cases radiation can be used to treat diseased organs or tumors.²¹

Modern industry uses radioisotopes in a variety of ways to improve productivity and, in some cases to gain information that cannot be obtained in

any other way. Selected radioactive sources are used in industrial radiography, gauging applications and mineral analysis. Short-lived radionuclides are used in flow tracing and mixing measurements. Gamma sterilization is used for medical supplies, some bulk commodities and increasingly for food preservation and sterilization. The half life of most of the industrial radioisotopes is longer, than the nuclear medicine radioisotopes therefore making them a little more useful in designing a RDD.²²

Table II-9. Most commonly used radioisotopes in industry.¹³

Radionuclide	Half-life	Radiation	Usage{Specific precaution level(s)}
Naturally occurring radioisotopes			
Hydrogen 3	12.3 y	β	Measurement of "young" groundwater (up to 30 years) Tritiated water is used as a tracer to study sewage and liquid wastes.
Carbon 14	5730 y	β	Measurement of the age of water (up to 50,000 years).
Carbon 36	1 3.1 y	$\beta \gamma$	Measurement of sources of chloride and the age of water (up to 2 million years).
Lead 210	22.3 y	$\alpha \beta \gamma$	Dating layers of sand and soil up to 80 years.
Artificially produced radioisotopes			
Scandium 46	83.9 d	$\beta \gamma$	Together with ⁶⁰ Co, ^{110m} Ag, ¹⁴⁰ La, and ¹⁹⁸ Au, is used in blast furnaces to determine resident time and to quantify yields to measure the furnace performance.
Chromium 51	27.8 d	γ	Together with ¹⁹⁸ Au and ¹⁹² Ir is used to label sand to study coastal erosion.
Manganese 54	312.5 d	γ	Together with ⁶⁵ Zn is used to predict the behavior of heavy metal components in effluents for mining wastewater.
Cobalt 57	270 d	γ	Together with ⁵⁷ Fe (stable isotope) is used in Mossbauer analysis
Cobalt 60	5.3 y	$\beta \gamma$	Gamma sterilization, industrial radiography and food irradiators. Also used for blast furnaces to determine resident time and to quantify yields to measure the furnace performance.
⁶⁵Zinc	243.9 d	$\beta \gamma$	Together with ⁵⁴ Mn is used to predict the behavior of heavy metal components in effluents for mining wastewater.
Bromine82	35.34 h	$\beta \gamma$	Hydrological tracing
Krypton 85	10.76 y	$\beta \gamma$	Reservoir engineering.
Strontium 90	28 y	$\beta \gamma$	Radiation gauges, automatic weighing equipment.
Technetium 99m	6.0 hr	γ	Together with ¹⁹⁸ Au is used to measure sewage and liquid waste movements.
Silver 110m	253 d	$\beta \gamma$	Together with ⁴⁶ Sc, ⁶⁰ Co, ¹⁴⁰ La, and ¹⁹⁸ Au are used in blast furnaces to determine resident time and to quantify yields to measure the furnace performance.
Cesium 137	30 y	$\beta \gamma$	Industrial radiography, radiation gauges, automatic level equipment, food irradiators and for radiotracing techniques in identifying sources of soil erosion and deposition.
Lanthanum 140	40.22 hr	$\beta \gamma$	Together with ⁶⁰ Co and ¹⁹⁸ Au in blast furnaces to determine resident time and to quantify yields to measure the furnace performance.
Cerium 144	284 d	$\beta \gamma$	Radiation gauges, automatic weighing equipment.
Promethium147	2.62 y	$\beta \gamma$	Radiation gauges, automatic weighing equipment. Consumer wristwatch luminous dials.
Ytterbium 169	31.8 d	γ	Industrial radiography
Thulium170	134 d	$\beta \gamma$	Industrial radiography
Iridium 192	74.2 d	$\beta \gamma$	Industrial radiography and together with ⁵¹ Cr and ¹⁹⁸ Au to label sand to study coastal erosion

Gold 198	2.7 d	$\beta \gamma$	Tracing of factory waste causing ocean pollution, trace sand movement in riverbeds and ocean floors. Blast furnaces to determine resident time, measure furnace performance. Together with ^{51}Cr and ^{192}Ir to label sand to study coastal erosion.
Plutonium 239	2.4 y	$\alpha \beta \gamma n$	As PuBe neutron sources for Borehole logging,
Americium 241	458 y	$\alpha \beta \gamma n$	As AmBe neutron sources for Borehole logging, and moisture measurement. . In Small quantities in smoke detectors.
Californium 252	2.65 y	$\alpha \gamma n$	Borehole logging (Don- not very much, too short a half-life)

IMPROVISED NUCLEAR DEVICE (IND)

An IND is made when terrorists acquire fissile material by purchase, diversion, or force for the purpose of fabricating a crude nuclear bomb. Two types of fissile material could be used for this purpose, highly enriched uranium (HEU) or plutonium, but the former would be far easier to make into a successful IND. It is generally assumed that successful INDs would have yields in the 10-20 kiloton range (the equivalent to 10,000-20,000 tons of TNT), while INDs that fizzled – i.e., did not detonate fully – might still produce a nuclear yield, which though far less powerful, could still cause very significant damage. A twenty-kiloton yield would be the equivalent of the yield of the bomb that destroyed Nagasaki and could devastate the heart of a medium-sized U.S. city, while causing fire and radiation damage over a considerably wider area.²³

NUCLEAR DETONATION

The immediate physical devastation could appear similar to that of the World Trade Center following the events of September 11, 2001. The two major injury and death producing forces in a nuclear detonation are blast forces and thermal radiation, both of which will cause injuries at much greater distances much greater than radiation injuries.²⁴

However, the dust and debris from this event will be highly radioactive. There would be thousands of people both contaminated and injured at the scene. In addition, there may be thousands of people in a large area potentially extending many miles outward from the initial point of attack with serious radiation exposures, due to radioactive fallout, although they may have no obvious physical injury or contamination. Radioactive fallout with potential for long-term health effects will extend over a large region far from ground zero. There would likely be many persons experiencing symptoms related to acute radiation syndrome.²⁴

Nuclear Detonation Effects Two basic types of blast forces occur simultaneously in a nuclear detonation blast wave. They are direct blast wave overpressure forces and indirect blast wind drag forces. Blast wind drag forces are the most important medical casualty-producing effects. Direct overpressure effects do not extend out as far from the point of detonation and are frequently masked by drag force effects as well as by thermal effects. The drag forces are proportional to the velocities and durations of the winds, which in turn vary with distance from the point of detonation, yield of the weapon, and altitude of the burst. These winds are relatively short in duration

but are extremely severe. They can be much greater in velocity than the strongest hurricane winds. Considerable injury can result, due either to missiles (shrapnel) – particularly glass fragments or to casualties being blown against objects and structures in the environment (blunt trauma).²⁴

Thermal burns will be the most common and extensive injuries, subsequent to both the thermal pulse and the fires it ignites. The thermal radiation emitted by a nuclear detonation causes burns in two ways, by direct absorption of the thermal energy through exposed surfaces (flash burns) or by the indirect action of fires caused in the environment (flame burns). Since the thermal pulse is direct infrared, burn patterns will be dictated by location and clothing pattern. Exposed skin will absorb the infrared, and the victim will be burned on the side facing the explosion. Skin shaded from the direct light of the blast will be protected.²⁴

The longest-range effect from the nuclear blast is sudden exposures to high-intensity visible light and infrared radiation of a detonation that will cause eye injury specifically to the chorioretinal areas. Individuals looking directly at the flash will receive retinal burns. 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.²⁴

Nuclear Detonation Radiation Exposure Injuries The effects of a surface or of a shallow subsurface burst will not be greatly different from those accompanying a low air burst. However, as increasing amounts of contaminated earth and debris are sucked up into the active cloud the hazard from the residual nuclear radiation in the early fallout increases. The only direct information concerning human casualties resulting from a nuclear explosion is that obtained following the air bursts over Japan. The Japanese experience applies only to the particular heights of burst and yields of the weapons exploded over Hiroshima and Nagasaki, and to the weather, terrain, and other conditions existing at the times and locations of the explosions.¹² A wide variety of ionizing radiation can interact with biological systems, but there are only four types of radiation associated with atmospheric and underground nuclear detonations of biological significance. In order of importance, they are gamma, neutron, beta, and alpha.⁶

Blast Effects Blast radiations, which are quite different from thermal radiation, and consist of gamma rays, neutrons, beta particles, and a small proportion of alpha particles. Most of the neutrons and part of the gamma rays are emitted in the fission and fusion reactions, (simultaneously) with the explosion. Even when the fireball touches the ground, the alpha and beta

particles are not very important. The initial nuclear radiation may thus be regarded as consisting only of the gamma rays and neutrons produced during a period of 1 minute after the nuclear explosion. Both of these nuclear radiations, although different in character, can travel considerable distances through the air. Both gamma rays and neutrons can produce harmful effects in living organisms.¹⁰

Radioactive Fallout In most circumstances, the whole-body dose from the gamma rays emitted by the early fallout will represent the major external hazard from the delayed nuclear radiation. The biological effects are then similar to those from equal acute doses of radiation. In addition, injury can arise in two general ways from external sources of beta particles. If the beta-particle emitters, e.g., fission products, come into actual contact with the skin and remain for an appreciable time, a form of radiation injury, sometimes referred to as "beta burn," will result. In addition, in an area of extensive early fallout, the whole surface of the body may be exposed to beta particles coming from many directions. Information concerning the development and healing of beta burns mostly was obtained from observations of the Marshall Islanders who were exposed to fallout in March 1954 (for detailed on external beta effects see "The Effects of Nuclear Weapons, Chapter XII-Biological Effects").¹⁰

RADIOLOGICAL DISPERSION DEVICES (RDD)

An RDD is any dispersal device causing purposeful dissemination of radioactive material across an area without a nuclear detonation. A terrorist or combatant with conventional weapons and access to radionuclides from sources such as a nuclear waste processor, nuclear power plant, university research facility, medical radiotherapy clinic or industrial complex can develop an RDD. This type of weapon causes conventional casualties to become contaminated with radionuclides and would complicate medical evacuation from the area. Damaged industrial radiography units and old reactor fuel rods can also cause significant local radiation hazards.^{25, 26, 27}

Basically, the principal type of dirty bomb, or Radiological Dispersal Device (RDD), combines a conventional explosive, such as dynamite, with radioactive material. In most instances, the conventional explosive itself would have more immediate lethality than the radioactive material. At the levels created by most probable sources, not enough radiation would be present in a dirty bomb to kill people or cause severe illness. For example, most radioactive material employed in hospitals for diagnosis or treatment of cancer is sufficiently benign that about 100,000 patients a day are released with this material in their bodies. However, certain other radioactive materials, dispersed in the air, could contaminate up to several city blocks, creating fear and possibly panic and requiring potentially costly cleanup. Prompt, accurate, non-emotional public information might prevent the panic sought by terrorists.²⁸

A second type of RDD might involve a powerful radioactive source hidden in a public place, such as a trash receptacle in a busy train or subway station, where people passing close to the source might get a significant dose of radiation.^D A dirty bomb is in no way similar to a nuclear weapon. The presumed purpose of its use would be therefore not as a Weapon of Mass Destruction but rather as a Weapon of Mass Disruption.²⁸

Impact of a RDD The extent of local contamination would depend on a number of factors, including the size of the explosive, the amount and type of radioactive material used, and weather conditions. Prompt detectability of the kind of radioactive material employed would greatly assist local authorities in advising the community on protective measures, such as quickly leaving the immediate area, or going inside until being further advised. Subsequent decontamination of the affected area could involve considerable time and expense.²⁸

What People Should Do Following an Explosion²⁸

- Move away from the immediate area--at least several blocks from the explosion--and go inside. This will reduce exposure to any radioactive airborne dust.
- Turn on local radio or TV channels for advisories from emergency response and health authorities.
- If facilities are available, remove clothes and place them in a sealed plastic bag. Saving contaminated clothing will allow testing for radiation exposure.
- Take a shower to wash off dust and dirt. This will reduce total radiation exposure, if the explosive device contained radioactive material.
- If radioactive material was released, local news broadcasts will advise people where to report for radiation monitoring and blood and other tests to determine whether they were in fact exposed and what steps to take to protect their health.

Sources of Radiation that could be used in a RDD Nuclear medicine, just like medicine involving drugs or chemicals, generates some wastes, both in the process of making radioactive isotopes and in treating patients. That waste is no different from wastes from any other application of nuclear science and technology and it comes in both high and low level radioactive forms. There are many choices of radioisotopes for performing human studies in nuclear medicine. Fortunately, with the exception of ¹³⁷Cs and a couple of other therapeutic nuclear medicine radioisotopes, the half lives are days to seconds with most being just a few hours.^{25,26}

III. INITIAL PATIENT MANAGEMENT, DECONTAMINATION AND TRANSPORTATION

Triage and disposition is challenging. For example, in the 1987 ^{137}Cs accident in Goiânia, Brazil, 8.3% of the first 60,000 people screened, presented with signs and symptoms consistent with acute radiation sickness: skin reddening, vomiting, diarrhea, etc. although they had not been exposed.²⁹

Mental Health professionals, ideally psychiatrists due to their background as physicians, should be an integral part of the teams that perform initial screening and triage. Referral to a mental health specialist is usually experienced as stigmatizing. The patient may feel that the physician has missed some important clue of contamination and is dismissing him prematurely.²⁹

DECONTAMINATION OF PERSONNEL AND CONTAMINATION MONITORING

Decontamination Line Setup Considerations The decon line should be established **uphill and upwind** from the event. The decon corridor should be established prior to the first responder being sent into the “hot” or contaminated area. What this means, essentially, is that there needs to be some forethought or preplanning about what should occur. The area should be surveyed, and the responder needs to focus on establishing a safe or uncontaminated area for the decon line. The next step that should occur is assembly of the decontamination crew and donning the necessary protective clothing.³⁰

Decon is simply the process of removing contamination from a victim. During the course of personnel (either ambulatory or nonambulatory) going through the decon line, the first responder must note the personnel readings on a Personnel Contamination Survey Sheet such as the one provided in the Documentation section. If the person has an injury that is life threatening, the injury is addressed before decon.³⁰

In a radiological event, there is a good chance that a significant number of the public will be exposed to low levels of radiation. It is unlikely that this exposure/contamination will lead to acute/immediate health effect. As such, the decontamination procedures should be commensurate with the hazards. For example, the victims' modesty should be considered; therefore, there is no need to remove the persons' clothing in an open, unprotected area. If a radiological incident did occur, the responder must determine if his organization can handle the number of contaminated personnel. If it is a radiological incident and it is greater than the organization capacity can handle, you have to know who to call for help.³⁰

Contamination Control All trash and waste generated or collected inside of a controlled area needs to be segregated, labeled and held until the time that enough qualified personnel and time is available to survey the waste to determine the proper disposal methods needed.³⁰

Where practical, wastewater contaminated with radioactivity should be labeled and controlled as radioactive waste. However, due to the expected large-scale impact that exists during a large-scale emergency, limited controls such as earthen berms to collect the wastewater or restricting the flow from drinking water sources may be the best reasonable method. Once the decon operation is done, the contaminated water will be disposed of in a manner described by local and state laws. For smaller events a locked approved Resource Conservation and Recovery Act (RCRA)-type storage area should be identified and designated for this purpose. Spillage to the soil or water supply should be minimized.³⁰

Scene Control Scene control may involve a larger area. A control problem will almost instantly be created by: decontamination line set up with numerous volunteers who all want to “help,” a huge press corps seeking information about the incident, and the public in general wanting to see what is happening. While the actual incident site may only be a city block in size, the area that will need to be controlled may be an area the size of several blocks. First responders should work closely with other support personnel such as HazMat technicians to make sure that the decontamination area is properly secured and controlled to prevent unwanted visitors.³⁰

For large-scale events, the decontamination/hotline facility needs to accommodate large numbers of people, have shower facilities, and large parking lots, if possible. Good candidates include stadiums, high schools, fitness centers, etc.³⁰

Decon lines in the city where the winds come from different directions or where dust is easily stirred up are more ideal if set up in an area providing indoor shelter, preferably with two big doors on the sides to serve as entrances and exits. This will help to protect personnel and responders from alpha and beta particles flying around or from gamma rays. An indoor casualty collection point would also be ideal.³⁰

A Rapid Response is required from first responders because of the potential of a large number of casualties following a radiological incident. Multiple trauma, thermal burns, and high levels of radiation in surrounding areas make immediate response necessary for life-saving purposes. The decontamination process must be completed properly, but must never take precedence over life-threatening conditions. Medical attention for more serious injuries will have priority over personnel decontamination. Individuals with minor injuries should be decontaminated, except for the wound(s), before

removal to a medical facility (as practical). In the event of a terrorist incident involving nuclear weapons of mass destruction, excessive delays could result in additional casualties. Remember to keep the following in mind:³⁰

CERCLA § 107 (d)(1) [often known as the “good Samaritan” provision] states:

“No person shall be liable under this sub chapter for costs or damages as a result of actions taken or omitted in the course of rendering care, assistance, or advice in accordance with the National Contingency Plan (NCP) or at the direction of an on-scene coordinator appointed under such plan, with respect to an incident creating a danger to public health or welfare or the environment as a result of any releases of a hazardous substance or the threat thereof.”

In other words, human life and health are responders’ primary considerations, but as soon as possible, all reasonable efforts must be made to contain and/or mitigate the contamination to avoid environmental consequences.³⁰

DECONTAMINATION

Decontamination is usually performed during the care of such patients 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. This ensures flexibility of response and action and will prevent delay in needed medical treatment. The simple removal of outer clothing and shoes, in most instances, will effect a 90% reduction in the patient’s contamination.^{24, 31, 32}

The presence of radiological contamination can be readily confirmed by passing a radiation detector (radiac) over the entire body. Open wounds should be covered prior to decontamination.^{24, 31, 32}

Prepare to decontaminate individuals exposed to fallout or other dusts from a radiological event: The objective of decontamination is to remove the particles of radioactive dirt or dust that have come in contact with the skin or clothes. Potentially contaminated clothing and other items should be removed or discarded prior to entering the shelter area. Simply taking a shower, washing effectively, and changing into clean clothes will generally decontaminate effectively. **Bleach should not be used to decontaminate, and never used directly on skin or to scrub skin or wounds.** Ideally, the water used for all purposes, including hygiene, should be stockpiled from safe sources and placed in sealed containers. The water used for decontamination must be contained and covered or drained outside of the shelter area to avoid shelter contamination.

One way to mentally prepare for the task of decontaminating a radioactively contaminated individual is to imagine that you are dealing with someone who has been contaminated with a large amount of bacteria which has a low pathogenic potential such as that contained in raw sewage. The sequence of steps you would follow to perform a safe and effective cleanup is similar in both cases.²⁷

Following any “quick decontamination” for the unusual high level of contamination, a more orderly management of the patient should begin. After stabilization, a careful survey of the naked body should begin. The amount of activity and its location are carefully recorded on anatomical burn type charts. Then, and only then, should an orderly decontamination begin.²⁷

- Decontamination should be performed with the following priorities:
- Wounds
- Orifices
- High-level skin areas
- Low-level skin areas

Radiological decontamination should never interfere with medical care.

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.^{24, 31, 32}

Contaminated Wounds. The cleaning of contaminated wounds will depend on the nature of the injury. Abrasions can be cleaned using standard decontamination techniques, whereas lacerations may require excision of the contaminated tissue if irrigation alone is not effective. Contaminated puncture wounds have sometimes been cleaned successfully using oral irrigators or water jets but typically are difficult to decontaminate because of poor access to the contaminants.^{24, 31, 32}

Wounds containing radioactive shrapnel must be handled with special care (it has occasionally been necessary to amputate heavily contaminated extremities when radioactive shrapnel could not be removed). All contaminated wounds can increase the level of internal contamination through absorption of radioactive materials directly into the circulatory and lymphatic systems.³²

Ingestion. If ingestion (as opposed to inhalation) of radioactive material is suspected, administration of aluminum hydroxide or magnesium carbonate antacids is indicated to reduce gastrointestinal absorption. If ingestion has occurred no more than 1 to 2 hours before evaluation, gastric lavage may be performed to reduce internal contamination. For large ingestions, cathartics (including enemas) may be administered to decrease gastrointestinal transit time.³²

Inhalation. Pulmonary lavage may be considered after significant inhalations of insoluble radionuclides but in general is rarely indicated.³²

DECON LINE SETUP

Different agencies have different ways of establishing a decontamination site. The types of contaminants, the number of casualties, and the type and quantity of equipment will drive the type of decontamination operation. Generally, a radiological decontamination operation will be a dry decontamination operation, except when a wet decon must be performed after a spot decon. This requires less equipment and a smaller area to conduct than the typical wet decontamination operation.³⁰

Dry Decon Dry decontamination excludes the use of water and is most commonly associated with decontaminating personnel involved in radiological/nuclear incidents. Without the use of water or liquid solutions, dry decon relies on the physical removal of radioactive contamination by removing clothing, brushing, or removing the contamination with tape. These methods are tried several times with a radiological survey performed after each decon attempt. In the event the dry decon procedure has been unsuccessful to reduce the contamination levels to less than twice the background (as was mentioned in the suggested release criteria), the responders need to perform spot decon.³⁰

Spot Decon Spot decon is very similar to dry decon except those areas on the body that read above the action levels are the areas that will get wiped down with a soapy wet cloth or will get sprayed with soapy water and wiped. In spot decon, the areas showing contamination are decontaminated with water. These methods are tried several times with a radiological survey performed after each decon attempt. In the event the spot decon procedure has been done on the person(s) and the radiation levels are more than twice the background (as was mentioned in the suggested release criteria), the responders need to perform wet decon.³⁰

Wet Decon Wet decon is done only when a reading is taken that shows above the action levels and after dry and spot decon have been performed, and the person(s) still shows contamination in the amount of two times the background levels of radiation. For wet decon, the water may be in a bucket or spray device, a firefighting hose, or a complex shower system. Typically, this can be done as part of the decon line and can be as simple as setting up a fire hose and spray nozzle to wash down responders and victims at the decon line. If, after the reading, the personnel's are not contaminated, then the people are moved along the decon line per the emergency procedure or the standard operating procedure that is in place. If the reading taken after the full wet decon still shows contamination, then the responder should perform a second full wet decon procedure. Another radiological survey

should be taken after the second full wet decon process. Once the radiological survey is taken, and if it still shows contamination, the victim should be taken to a special evaluation section. If there is no more contamination, then the person is ready to depart the decontamination line per organization procedures.³⁰

The process of decontamination should not result in skin damage, which could increase the chance of a contaminant entering the body. Decontamination procedures should be terminated before reaching this point even if it means leaving some contamination on the body. Fresh clothing, bedding etc. must be provided to the victim after bathing. Waste and wastewater must be contained and controlled.

Table III-1 Personnel decontamination techniques.³⁰

PERSONNEL DECONTAMINATION					
<i>Begin with the first listed method for that body part and then proceed step by step to the more severe methods, as necessary.</i>					
Method	Body Part	Action	Technique	Advantages	Disadvantages
Masking Tape	Skin, hands unless area is sensitive or has a lot of hair	Removes contaminated dust and dirt.	Use the “sticky” side of a reverse rolled piece of masking tape to remove dirt and any loose contamination. If a meter shows the contamination was not removed, then cleanse the area with moistened paper towels. Lukewarm water should be used, if possible. Do not use hot water (it opens pores in the skin).	Quick and effective for most radioactive contamination. Only generates very small amounts of contaminated liquid waste compared to washing.	Some areas of skin are sensitive and can become irritated by the tape being pulled off. Will not work on liquid contamination.
	Hair	Same as above.	Wash several times. If contamination is not lower to acceptable levels shave the head and apply skin decontamination methods.	Same as above.	Same as above.
Soap and water	Skin and hands	Emulsifies and dissolves contaminants.	Wash 2 to 3 minutes and monitor. Do not wash more than 3 to 4 times. Do not use hot water (it opens pores in the skin). Use lukewarm water.	Readily available and effective for most radioactive contamination	Continued washing will defeat the skin. Indiscriminant washing of other than affected parts may spread contamination.
	Hair	Same as above.	Wash several times. If contamination is not lower to acceptable levels shave the head and apply skin decontamination methods.	Same as above.	Same as above.
Lava soap, SOFT brush, water	Skin and hands	Emulsifies dissolves, and erodes contaminants.	Use light pressure with heavy lather. Wash for 2 minutes, 3 times. Rinse and monitor. Use care not to scratch or erode the skin. Apply lanolin or	Readily available and effective for most radioactive contamination	Continued washing will abrade the skin.

			hand cream to prevent chapping.		
Clothing detergent (plain)	Skin and hands	Same as above.	Make into a paste. Use with additional water with a mild scrubbing action. Use care not to erode the skin.	Same as above.	Continued washing will abrade the skin.
Mixture 50% Detergent 50% Cornmeal	Skin and hands	Same as above.	Make into a paste. Use with additional water with mild scrubbing action. Use care not to erode the skin.	Slightly more effective than washing with soap.	Will defat and abrade the skin and must be used with care.
Sweating	Skin of hands and feet	Physical removal by sweating.	Place hand or foot in plastic glove or booty. Tape shut. Place near source of heat for 10 to 15 minutes or until hand is sweating profusely. Remove glove and then wash using standard techniques. Or gloves can be worn for several hours using only body heat.	Cleansing action is from the inside out. Hand does not dry out.	If glove or booty is not removed shortly after profuse sweating starts and parts washed with soap and water immediately, contamination may seep into the pores.
Flushing	Eyes, ears, nose, and mouth (NOTE: This is the first method to use for the eyes, ears, nose, and mouth)	Physical removal by flushing.	Roll back the eyelids as far as possible, flush with large amounts of water. If isotonic irrigants are available, obtain them without delay. Apply to eye continually and then flush with large amounts of water. (Isotonic irrigant [0.9% NaCl solution]: 9 grams NaCl in beaker, fill to 1,000 cc with water.) Can be purchased from drug suppliers, etc.	If used immediately will remove contamination May also be used for ears, nose, and throat.	When using for nose and mouth, contaminated individual should be warned not to swallow the rinses.
	Wounds	Physical removal by flushing.	Wash wounds with large amounts of water and spread edges to stimulate bleeding, if not profuse. If profuse, stop bleeding first, clean edges of wound, bandage, and if any contamination remains, it may be removed by normal cleaning methods, as above.	Quick and efficient if wound is not severe.	May spread contamination to other areas of body if not done carefully.

Handling Injured Personnel Radioactive Decontamination should NEVER be undertaken on an unstable, injured victim. Contaminated patients will die

from medical instability, not contamination. If lifesaving maneuvers are necessary, wear trauma gear, cover the patient with sheets, cut the clothing to expose essential body areas, perform stabilization procedures, and transport if necessary. Most of the time, contaminated victims bypass responders anyway and present themselves directly to the hospital.³⁰

First responders CANNOT prevent all contaminated victims from reaching the medical facility. Receiving contaminated patients should be a realistic expectation of all medical facilities. Because of this, decontamination procedures should be part of the operational plans for all medical facilities that may receive ambulatory and nonambulatory victims. Response personnel can protect themselves by taking universal precautions and wearing either a standard surgical mask or high-efficiency particulate air (HEPA) respirator N95 (a.k.a. tuberculosis mask).³⁰

When their medical condition permits, victims should be moved to the control line and separated into contaminated and noncontaminated areas where they may receive further care and radiological monitoring. Even if the incident scene is contaminated, the victims might not be. All persons who have been in the controlled area should be detained for radiological monitoring. Protective clothing should be removed at the control line.³⁰

Vehicle Monitoring Vehicle monitoring systems for beta/gamma radiation is available in a configuration similar to that of personal portal monitors. In fact, some personal portal monitors can be configured to monitor vehicles (with less sensitivity). Vehicle monitoring could be a large part of a response if the public uses their own vehicles to evacuate or if major roadways are affected. Additional sets of vehicle monitors should be obtained, with portable instruments used as backups. Four sets should be considered, as this would allow monitoring of two roadways (one monitoring system on each end).³⁰

Vehicle decontamination differs from personnel decontamination in that there is little urgency to immediately perform the decontamination. Monitoring and decontamination of vehicles may have to wait until personnel and equipment are available for performing these services, especially if there are large populations needing monitoring, limited monitors, extremely high levels of contamination, or adverse weather conditions. Contamination levels have not been established for acceptable levels for vehicles after an event. It is generally assumed that the commonly accepted release values would be used, however; a higher value may be considered if the effort required to decontaminate to practical levels is too time intensive or adequate resources are not available. Contaminated vehicles may be addressed after the emergency has passed and personnel are available to devote attention to these issues.³⁰

If equipment or vehicles are being surveyed, the “hands and feet principal” could be applied, meaning the tires/wheel wells should be checked first. Then a logical sequence is door handles, floorboards, steering wheel, air filter etc. Pay special attention to any areas where people place their hands or feet.³⁰

Beta-gamma monitoring Portal monitors may be used when the gamma component of the contamination is adequate for easy detection. For aged fission products, release surveys can only be performed using hand-held contamination monitors and require long monitoring times. During an emergency, surveying a vehicle will take lower priority than addressing other contamination issues such as contaminated personnel.³⁰

Alpha monitoring The range of alpha radiation prohibits the use of portal monitoring. Portable instruments will be required for alpha radiation monitoring. Vehicles will have to be held until later stages of the event when resources can be devoted to this effort. If the contamination includes known gamma emitters, the alpha contamination level can be inferred from the gamma monitoring results provided by portal monitors.³⁰

Monitoring of Personal Property Though people are encouraged to minimize personal possessions brought out during evacuation, some personal effects monitoring will be required. Current technology will require portable survey of these effects. However, technology exists which could allow automation with minimal effort (similar to inspection conveyors at airports). This type of system should be developed for beta/gamma radiation monitoring. The range of alpha radiation would make a similar system for alpha monitoring much more challenging.³⁰

Clothing Contaminated clothing should be removed and replaced with clean clothing. This requires supplies of clean clothing to be available or easily purchased. Replacement of outer clothing may be adequate for removing most of the contamination in all but the most severe cases. Plans should be made before the event regarding the procurement of replacement clothing for persons exiting a contaminated area. One method of providing replacement clothing would be to request assistance from department stores, sporting goods distributors, hospitals, and other organizations that may have abundant supplies of clothing for outfitting large numbers of people.³⁰

Glasses/dentures/prostheses/jewelry, etc. Glasses, contact lenses, dentures, prostheses, jewelry and other essential personal items can be monitored using a small article monitor or tool monitor relying on scintillation detectors for detection of gamma emitters. The return of some personal items to individuals may be essential, after an initial decontamination procedure.³⁰

Tools and other hand-carried items Laptop computers, family keepsakes, and photographs may be carried by individuals evacuating an event site. Items exhibiting extensive contamination with alpha or beta emitters will probably have to be bagged and set aside until resources are allocated for monitoring these items. During the evacuation, these items will be collected for later survey. Some means of identifying the items should be implemented to facilitate getting them back to the owner after being surveyed. Cell phones, laptop computers, and other small items may be monitored with portable instruments or small article monitors and/or decontaminated by sanitary wipes if the contamination levels permit.³⁰

Medications Persons on prescription medication such as insulin, heart medication, blood pressure medication and other critical medications would be expected to bring their medications with them. In cases where the event site cannot be reentered and the medicine is needed, the local public safety agency will need the ability to quickly procure and distribute critical medications. For medications, which are not readily available, the medication taken from the event site may be decontaminated as long as it was contained within the sealed prescription bottle during the time of the release.³⁰

Monitoring and Decontamination of Pets and Animals This is an issue that has not been addressed in any detail. Evacuees are typically instructed to leave their pet with a three-day supply of food and water. It is anticipated that many people will want to take these “member of their family” with them. Even if they do not, there will be a significant re-entry demand after three days.³⁰

Monitoring for gamma emitters can be accomplished using portal monitors or hand-held portable survey instruments. Beta and alpha emitters may require the use of hand-held portable instruments. Surveys times for animals may be delayed due to other priorities (citizen treatment) and the difficulty of keeping the animals still and the possibility of contamination being hidden within the hair. Decontamination of pets will include washing them with soap and water, or simply using a garden hose to decontaminate. Hair, decontamination wash water, excreta, and any other potentially contaminated materials should be collected and held for proper storage and disposal. Pet owners will not accept sacrificing their pets if the contamination is not life threatening to the animal. It is likely that pets will be decontaminated to levels preventing the spread of contamination to humans and will be allowed to return to non-detectable levels by natural processes.³⁰

In addition, farm animals may also need to be surveyed at some point. These animals may not cooperate in using standard portal monitors or handheld survey methods. Research and Development should be capable of providing “counting

cages” for monitoring beta/gamma contamination. Alpha will likely require portable instrument surveys. Animals will need to be confiscated and removed from the food supply. Contamination limits for pets and farm animals should be the same as for unconditional release if possible. This is not always possible, so alternate contamination values could be established. Animals are not at risk at a higher contamination level and the limits for humans would not necessarily apply. Precautions will need to be made to contain the contamination excreted or sloughed off by the animals. This can be collected and treated as waste and dealt with later.³⁰

DOCUMENTATION

A means of documenting the individual and property surveys and results will need to be implemented. When surveying large numbers of people, vehicles, pets and or personnel property the task of documenting survey results will undoubtedly become burdensome. Preplanning needs to occur to determine how surveyed individuals will be tracked. One suggestion would be to use driver’s license numbers, student ID numbers, or in the case of children, a number associated with the parent or guardian for each child. For individuals without readily available identifiers, other means of tracking the people will have to be implemented. In these cases, taking the individual’s name, date of birth, place of birth, address, and phone number should be adequate for uniquely identifying that individual. This will be necessary if follow-up or verification needs to be performed. All persons, pets, vehicle and personnel property surveyed, whether contamination is found or not, will need to be documented, this will help to provide information after the event is completed if litigation is encountered. If significant contamination is present, a dose assessment will be needed to determine the dose to the individual.³⁰

An example of a “Personnel Contamination Survey Sheet is listed below. Personnel survey records should indicate:³⁰

- The name of the individual surveyed (including date of birth, place of birth, address, and phone number should be adequate for uniquely identifying that individual.)
- The locations and levels of any contamination detected (including units – cpm, mR/hr)
- The type of instrument used for the survey
- The nature of any instructions given to the contaminated individual concerning decontamination procedures (if the individual is to decontaminate himself) or any descriptions of decontamination procedures performed by the survey personnel
- Name of person performing the survey

In addition to the information indicated on the form, there is also space for the name of the surveyor who detected the contamination, the time of the survey, the serial number of the instrument, and whether or not bioassay samples were

collected. The information about the instrument and surveyor would be used if there were questions later about the exact location of the contamination or about the accuracy of the measurement. To indicate the location of the contamination on the person, draw a numeral "1" for the first location on the diagram of the body (front or back side). Then write the instrument reading (e.g., "1,250 cpm" not just "1,250") next to the "1" in the measurements box. Use the numeral "2" for the second contamination location, etc.³⁰

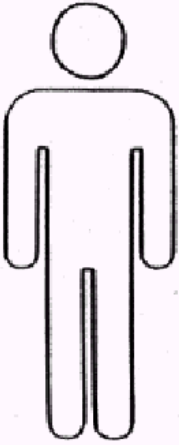
- Survey records for pets, vehicles and personnel property should indicate:
- The name of the owner of the item being surveyed
- Description of the Item (including License Number, Serial Numbers)
- The locations and levels of any contamination detected (including units – cpm, mR/hr)
- The type of instrument used for the survey
- The name of the person performing the survey
- The nature of any instructions given to the owner of item concerning decontamination procedures (if the individual is to decontaminate himself) or any descriptions of decontamination procedures performed by the survey personnel

PERSONNEL CONTAMINATION SURVEY SHEET

Name: _____ Date/Time: _____ Team: _____

Mark contamination locations on the diagrams below. Bioassay Collected: Yes No

FRONT



Measurements:

1. _____

2. _____

3. _____

4. _____

5. _____

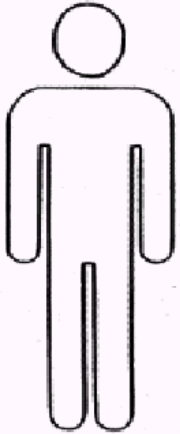
6. _____

7. _____

8. _____

9. _____

BACK



Measurements:

1. _____

2. _____

3. _____

4. _____

5. _____

6. _____

7. _____

8. _____

9. _____

Comments: _____

Monitored by: _____ Instrument: Type: _____ Number: _____

Figure III-2 Personnel Contamination Survey Sheet³⁰

PORTAL MONITORS

Portal monitors can detect gamma contamination on an individual or any item passing through it. It is better suited for detecting higher energy gamma emitters, and is not well suited for detection of beta emitters, especially low energy ones. Most alpha emitting radionuclides cannot be detected with portal monitors. The requirements in “Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in support of Nuclear Power Plants” NUREG-0645 FEMA-REP-1 Rev 11 (REP-1) should be used for establishing criteria for MDA for these instruments.³⁰

Using REP-1 a portal monitor (stand-alone whole-body personal contamination monitor) used to monitor individuals exposed or potentially exposed to a plume of radioactive material must have the capability to detect one microcurie (μCi) of radionuclides that emits beta and gamma radiation (radionuclides such as those that may be released following a reactor accident) in the form of surface contamination with a widespread non-uniform distribution over an individual. This current detection limit guidance is based on a 1 μCi of Cs-137. This criterion assumes a release involving fresh fission products from a reactor accident; however, more restrictive criteria could be considered to account for radiological event involving a mixture of beta-gamma emitters without the more easily detectable gamma emitters.³⁰

PORTABLE INSTRUMENTS

The primary purpose for performing radiological surveys is to determine the extent of any existing health hazards, establish protective control boundaries, and provide data on which to base decontamination requirements.³⁰

Portable instruments are designed for detecting beta and alpha emitters. Consideration should be given to instruments with both alpha and beta detection capabilities for releases involving both types of radiation.³⁰

The types of radiological surveys that can be performed on-scene are area surveys, personnel surveys, and equipment surveys. Each of these surveys have a different purposes, and as a result, are performed for different reasons. The differences between the survey types are:³⁰

Area surveys may involve the determination of fallout patterns on the ground, levels of airborne activity, or contamination patterns to establish hazard control zones. Area surveys are normally done once the HazMat technician has gathered information from the appropriate agency/agencies about what is happening on-scene, and spoken with those at the command center about any information they have regarding the incident.³⁰

Personnel surveys are performed to detect the presence of contaminated material on the body's surface, in body openings (e.g., nose and ears), or, in

the case of casualties with traumatic injury, contamination in wounds. The results of personnel surveys are used to evaluate health hazards, to establish decontamination requirements, and determine the level of medical treatment. Equipment/material surveys are conducted primarily to ascertain requirements for decontamination.³⁰

USING PORTABLE INSTRUMENTS FOR PERSONNEL CONTAMINATION SURVEYS

Using a hand-held survey instrument to conduct a personnel contamination survey is the first step in determining which individuals need to be decontaminated. In the field, surveying will be done with hand-held instruments. The recommended instrument for this task is a survey meter with a sensitive probe that can detect alpha, beta, and gamma radiation. An instrument with a scintillator or **Geiger-Mueller detector with the pancake probe** (not the hot dog probe) should be used to detect low levels of contamination on people or equipment. The pancake probe is five-times more sensitive than the hot dog probe, which cannot detect alpha radiation.³⁰

When surveying personnel or equipment, the pancake probe should be held as close as practical from the surface being surveyed without actually touching. Remember that an alpha particle travels only $\frac{1}{4}$ inch to two inches in air, so if the probe is further away, it will not detect alpha contamination. Also, a thin layer of water, dirt, clothing, bandages, blood, etc., will block the alpha radiation and prevent the alpha-emitting contamination from being detected. In addition, the probe should be moved very slowly over the surface being surveyed. A general guideline is one-probe diameter per-second or one to two-inches per second. If personnel are being surveyed, the most likely places for contamination are the feet and hands. Be careful not to put the probe under the surface being surveyed, or contaminated dirt, etc., may fall onto the probe and contaminate the probe itself. After the hands and arms are checked, survey the rest of the body, beginning at the top of the head and working down. The front side of the person is checked first and then the backside.³⁰

NOTE: The responder with the radiation detection instrument should direct the movements of the person being surveyed. The responder operating the instrument should never move. Always begin the survey with the meter setting on the lowest scale.³⁰

Portable Instrument Basic Operations Check the survey meter prior to use.³⁰

- Verify that the instrument is in service, set to the proper scale (the lowest or most sensitive setting), and check if the audio output can be heard during surveying. Try to limit handling of the meter and probe until you have checked your hands for contamination.
- Turn the Instrument **ON** and that the batteries are good.
- Set the knob to the lowest scale.

- Set the **Audio** switch to **on**. You should be able to hear an occasional audio click, even when the meter is measuring “clean/uncontaminated” background levels.

Check your hands for contamination before handling the probe. ³⁰

- Leave the probe attached to the holder on the meter, and remove the cover from the pancake probe.
- Place the palm of one hand up to the sensitive area of the probe for approximately five seconds. Then move the hand slowly in front of the probe to scan the fingers and the back of the hand.
- Repeat this procedure with the other hand.
- Repeat step 2 if you touch any potentially contaminated surface

Take a background measurement for reference. If you are not given preestablished contamination limits for surveying (such as those given in the sample table below), then take a background measurement in a clean area. Use this background reading as your reference, and use **twice** this background reading as the contamination limit. **If any measurement is greater than twice the background reference reading, then consider the person or item contaminated.** ³⁰

- Turn the Instrument ON and complete the battery test (**BAT**) to check that the batteries are good.
- Set the knob to the lowest scale.
- Measure the background radiation level for approximately 60 seconds. It is normal for the value to vary some during the measurement. Write down what appears to be the average value or most common reading during the 60-second interval.
- Use this average value as the background reference. Typical background readings are about 40 to 100 cpm or 5 to 20 $\mu\text{R/hr}$ (0.005 to 0.02 mR/hr). When using a probe that can detect alpha or beta radiation (hot dog probe with beta window open or the pancake probe), make the reading in units of counts per minute. Use the mR/hr readings only when the probe can only detect gamma radiation (such as the hot dog probe with the beta window closed).
- **Use a twice-background value as the contamination level** if another trigger limit is not supplied by procedures of qualified personnel. Write down these two values with the units (cpm or mR/hr) for future reference. For example:

Background	35 cpm (or 0.035 kcpm)
Contamination level	70 cpm (or 0.070 kcpm)

Hold the probe less than $\frac{1}{2}$ inch from the surface being surveyed for beta and gamma contamination, approximately $\frac{1}{4}$ inch for alpha contamination (or for alpha, beta, and gamma contamination). If it is not possible to maintain a $\frac{1}{4}$ -inch separation, then hold the probe as close as possible without touching or dragging

the probe across the surface. **Remember that even a thin layer of water, dirt, blood, or clothing will block alpha radiation and prevent detection of the alpha source contamination.**³⁰

- Move the probe slowly above the surface, approximately one probe diameter per second, or about two inches per second.
- If the count rate increases during surveying, pause for five to ten seconds over the area to provide adequate time for instrument response.
- If you can hear the audible clicks from the meter, then you can focus your attention on the probe and surveying technique while you listen for an increase in the clicking rate. If the clicking rate increases, pause and look at the meter dial.
- If the count rate increases to a value greater than the preestablished contamination limit or greater than twice-background if no limits were preestablished, then the person will need to be decontaminated.
- The whole-body survey should take at least two to three minutes to check one person.

Table III-3 Personnel Contamination Trigger Levels³⁰

Location	Alpha Emitters	Beta/Gamma Emitters
Nasal or mouth smears (Combined activity in both nostrils)	20 dpm (40 dpm for uranium)	200 dpm
Facial contamination	200 dpm	4,000 dpm
Skin breaks*	Any detectable activity	Any detectable activity
Head, neck contamination	2,000 dpm	40,000 dpm
Contamination inside respirator	Detectable activity inside respirator after use	

*Bioassay procedures (biological assay samples to check for internal contamination) should be initiated for any puncture wound while handling unsealed radioactive sources, while handling any leaking radioactive sources, or while working in a contaminated area.³⁰

Personnel Contamination Survey Procedure

In performing a personnel survey, the individual to be monitored stands with legs spread and arms extended. The responder should begin the survey at the head, subsequently surveying the upper trunk, arms, lower trunk, and legs. The individual being surveyed is asked to turn to the back, and the procedure is repeated. As in equipment and area surveys, care must be taken not to permit the detector probe to touch any potentially contaminated surfaces.³⁰

It is not necessary to perform the personnel contamination survey in exactly the order shown in the Sample Personnel Contamination Survey Procedure, but a

consistent procedure should be followed to help prevent accidentally skipping an area of the body. Tell the person to stand erect, with feet spread slightly, and arms extended with palms up and fingers straight out. Pause the probe for about five seconds at locations most likely to be contaminated.³⁰

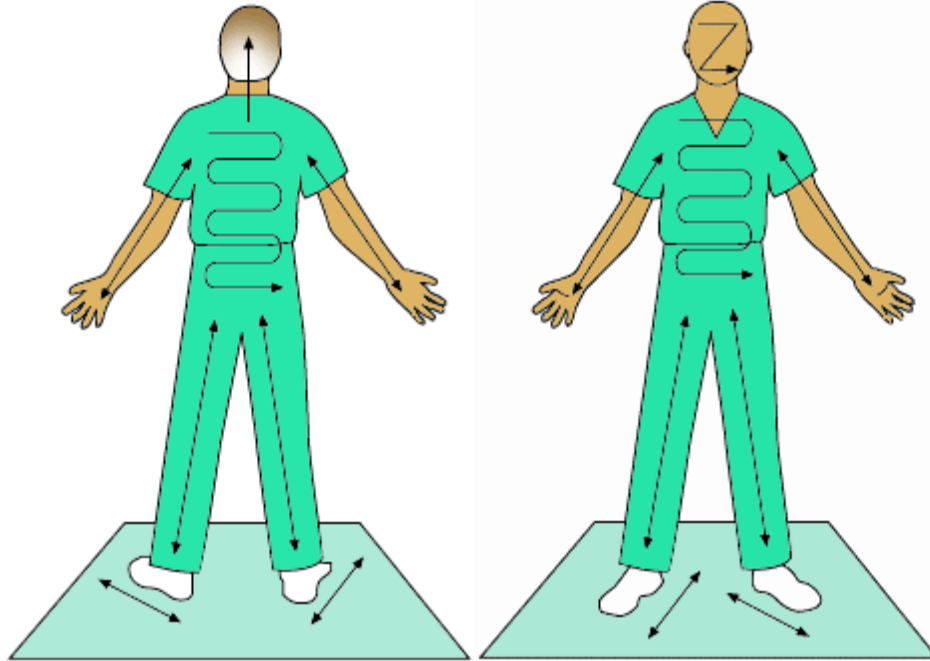


Figure III-4 Personnel Contamination Survey Procedure.³⁰

- Top and sides of head, face (pause at mouth and nose for approximately five seconds; this may indicate internal contamination)
- Front of the neck and shoulders
- Arms (pause at each elbow)
- Hands (pause at palms for approximately five-seconds)
- Chest and front abdomen
- Front of the legs (pause at each knee)
- Shoe tops
- Have the person being surveyed turn around
- Back of the head and neck
- Back of Arms (pause at each elbow)
- Back of Hands (pause at palms for approximately five-seconds)
- Back and rear of abdomen (pause at the seat of pants)
- Back of the legs (pause at the knees)
- Shoe bottoms (pause at sole and heel)

Return the probe to its holder on the meter when finished. **Do not** set the probe down on the ground. **The probe should be placed in the holder with the sensitive side of the probe facing to the side or facing up so that the next**

person to use the meter can monitor his/her hands before handling the probe.³⁰

The most common mistakes made during the survey are:

- Holding the probe too far away from the surface (should be about ½ inch or less)
- Moving the probe too fast (should be about one-probe diameter per second or 1 to 2 inches per second)

Potential Portable Instrument Problems for Responders When instruments have not been used for an extended period of time, a battery check should be performed. Additionally, a check of the overall condition of the instrument is warranted. The only way to be confident that an instrument is performing correctly is to response check the instrument to a known source of radiation (e.g., a small radiation check source provided by the instrument manufacturer). If the instrument responds within $\pm 20\%$ of a previously performed response check, then a certain degree of confidence can be placed with the performance of the instrument.³⁰

Radiation meters should be checked and calibrated annually by a certified calibration lab to ensure the equipment is operational and giving correct readings. As radiation detectors age, some of the components deteriorate. If an instrument has been on a shelf, untouched, for ten years, do not rely on those meters. They may not work at all, or they may read twice or half the actual radiation levels, etc.³⁰

If no instrument is available, try to obtain the information on any Department of Transportation (DOT) shipping paperwork or radiation labels, if applicable. An Emergency Response Guide (ERG) can also provide guidance for dealing with radiological/nuclear accidents involving shipments (see ERG 163). Placards on the vehicle are only present in very high radiation fields. Radiation cannot be seen, felt, tasted, or smelled. However, very strong radiation sources (thousands of curies [Ci] or tens of terebecquerel [TBq], or higher) may generate their own heat and be warm or hot to the touch. Do not handle or pick up suspected radioactive material to see if it feels hot. You can unnecessarily expose your hands and body to high doses of radiation. A suspicious metal object or container that is warmer than its environment may contain highly radioactive material.³⁰

TRIAGE

In conventional triage, patients are assigned to one of the following priority categories, depending on the nature and extent of their injuries³

- **T1 The immediate treatment** (RED) group includes patients who have a high chance of survival if they are given immediate life-saving treatment or surgery that is relatively quick and uncomplicated.

- **T2 The *delayed treatment*** (YELLOW) group includes patients who may need major surgery, but who can be sustained on supportive treatments until surgery is possible.
- **T3 The *minimal treatment*** (GREEN) group includes patients with relatively minor injuries who can care for themselves or who can be helped by untrained personnel.
- **T4 The *expectant category*** (BLACK) includes patients with serious or multiple injuries requiring extensive treatment, as well as patients with a poor chance of survival. This group should receive supportive treatments that are compatible with resources, including large doses of analgesics.

Medical providers must be prepared to adequately treat injuries complicated by ionizing radiation exposure and radioactive contamination. Nuclear detonation and other high-dose radiation situations are the most critical (but less likely) events as they result in acute high-dose radiation.⁵

Acute high-dose radiation occurs in three principal situations:

- A nuclear detonation which produces extremely high dose rates from radiation during the initial 60 seconds (prompt radiation) and then from the fission products in the fallout area near ground zero.
- A nuclear reaction which results if high-grade nuclear material were allowed to form a critical mass (“criticality”) and release large amounts of gamma and neutron radiation without a nuclear explosion.
- A radioactive release from a radiation dispersal device (RDD) made from highly radioactive material such as ⁶⁰Co or ¹³⁷Cs which can result in a dose sufficient to cause acute radiation injury.

In a nuclear disaster, triage decisions cannot be made on the evidence or probability of conventional injury alone. When significant radiation exposure is combined with conventional injuries, there may be a dramatic shift of patients to the expectant category (Table III-1). In order to make an appropriate decision, the triage officer must recognize the symptoms of ARS and understand the difficulties in estimating radiation exposure from clinical findings.³³

Cutaneous Phenomena. Information about the cutaneous changes after ionizing radiation exposure comes mainly from accidental or therapeutic high-dose local radiation exposures and, to a lesser extent, from studies of the victims of the 1986 nuclear reactor accident in Chernobyl, USSR, and the 1987 cesium-137 accident in Goiânia, Brazil. Skin injury in those events resulted from very intense local irradiation or direct contact of the skin with radioactive material. Burns among casualties at Hiroshima and Nagasaki in 1945 were caused by heat rather than radiation exposure.³³

Gastrointestinal Phenomena. A sense of fatigue and malaise associated with nausea and loss of appetite is characteristic even of relatively low-dose radiation exposure (1-2 Gy). The abrupt onset of nausea and vomiting occurs

with acute high-dose radiation in the range of 5-10 Gy. These initial symptoms may be followed by a short latent period of 1-2 days. The severity of initial symptoms, including diarrhea, serves as a useful index of probable outcome, as does the rapidity of onset or a delay in the appearance of symptoms. Following the latent period, an increase in vomiting, diarrhea, and anorexia, as well as dehydration and signs of infection, can be expected. An abrupt onset of bloody diarrhea after acute high-dose radiation indicates lethal exposure. If less-acute doses are received, diarrhea may not appear for several days or a week after exposure. The onset of diarrhea within a week of exposure is usually associated with death.³³

Burn Injury. Burns are judged by the size of the burn in relation to the whole body and by the depth of the burn injury. Different methods exist to calculate the extent or size of a burn injury. The most common method, which provides a quick estimate of burn size, uses the "Rule of Nines," where the body is divided into areas equaling multiples of nine percent of the total body surface area. The palm of your hand, for example, is equal to about one percent of your body's surface area. The head and arms are each equal to nine percent of the body surface. The chest and back are each 18 percent (two X nine percent). Each leg is 18 percent (two X nine percent). This totals 11 nines, or 99 percent. The heads of infants and small children are in relatively larger proportion to the total body surface area, and the limbs are in smaller proportion than adults limbs. The total body surface area of a burn is referred to as TBSA. The TBSA and burn depth analysis are recorded on a hospital chart known as a "burn diagram." Determining the percent of body surface area burned is important for correct fluid replacement. A more severe hematopoietic subsyndrome is likely if partial-thickness burns involve more than 10% of the body surface.³⁴

Blast Injury. Dynamic overpressure from the explosion of a nuclear weapon will induce overt crush injuries and occult internal bleeding. The triage officer should suspect occult traumatic injuries, which will likely place the irradiated patient in the expectant category.³³

Eye Injury. Eye injuries from a thermonuclear flash may be as minor as transient blind-ness (for a few seconds to minutes) or a permanent retinal scar in which peripheral vision is spared. These are minimal injuries. However, permanent foveal damage with 20/200 visual acuity may occur if the victim focuses directly on the nuclear fireball. A variety of eye injuries resulting primarily from protracted high-dose radiation exposure was observed among firefighters at the Chernobyl reactor accident. These injuries will most likely lead to permanently impaired vision.³³

RESPONSE TO A RDD

Unlike a nuclear detonation, RDDs are likely to affect relatively small areas, and the most effective protection is to leave the affected area. Do not shelter-in place.

If there is a possibility that the suspected device has explosives attached, it should be treated as a bomb. Do not reenter the contaminated area. Individuals evacuating a contaminated area should be decontaminated immediately and seek medical attention. Decontamination is most easily achieved by simply taking a shower, washing effectively, and changing into clean clothing.

Do not use Potassium Iodide (KI). Use of potassium iodide: KI is an antidote almost exclusively used in the aftermath of reactor incidents. ***KI only counters the effects of radioactive iodine internally ingested or inhaled.***³⁵

Unfortunately radioactive materials can range from conventional weapons isotopes, to materials used in medical and industrial processes. KI should be administered only by health professionals and only if the radiation contamination is identified as being radioactive iodine. With the radioactive isotope unknown, KI administration is not recommended. Potassium iodide, without the presence of radioactive iodine, will cause negative health effects in certain groups of people. Radioactive iodine is very difficult to obtain, and is not considered a likely isotope to be used in an RDD incident.³⁵

The area impacted during the emergency phase by an explosive RDD where acute health effects are possible, as well as lesser affected areas that have levels of contamination that meet or exceed the criteria of 10–50 mSv for evacuation (U.S. EPA 1992), can be assumed to be bounded within a 500 m radius (Harper et al. 2006) and might be considerably smaller, depending on the amount of radioactivity in the weapon and the kinetics of the explosive.³⁶

- If there is no knowledge of the size of the initial radiological source, or if it is known (from law enforcement intelligence sources earlier) that the device.
- contained a very large radiological source— greater than 370 Tbq (10,000 Ci)—establish a high zone boundary at 500 m in all directions from ground zero. Do not decide anything based on the perceived wind direction, especially in an urban setting where the wind field can be very complex. This boundary definition is consistent for both alpha and beta-gamma emitters;
- Evacuate the high zone to control the dose to the population therein. Control access to the high zone to limit the number of non-contaminated persons entering the most contaminated area and exclude nonessential people;
- Confirm the outer boundary of the high zone when the actual 10 mSv h₋₁ line is determined from instrument readings. In most cases, this will be much closer to the source than 500 m;
- Define the outer boundary of the high zone at 10 mSv hr₋₁ because this has the advantage of establishing the point where emergency personnel can stay, unrestricted, for 4–5 h without exceeding 50 mSv from external exposure, unless a more pragmatic location further away reduces the dose rate to As Low As Reasonably Achievable (ALARA). But, for saving

- lives and protecting critical infrastructure, 10 mSv h^{-1} is an acceptable radiation level if occupancy near this boundary is necessary for the first few hours of the crisis. (Note: Even though the outer boundary of the high zone is recommended at the 10 mSv h^{-1} boundary, ballistic fragments or isolated high spots that greatly exceed 10 mSv h^{-1} could be located inside or outside the zone. For example, ^{60}Co in metallic form tends to fracture into large pieces and partially aerosolize (Harper et al. 2006);
- If it is known (from prior law-enforcement intelligence) that the source is smaller than 370 Tbq (10,000 Ci), establish the initial high zone boundary at 250 m without waiting for measurements from instrumentation;
 - Once the high zone is defined, establish the outer boundary of the medium zone where the radiation level is in the range of $0.01\text{--}0.1 \text{ mSv h}^{-1}$. Definition of this boundary with this range gives first responders flexibility to set up the outer boundary of the medium zone at the most pragmatic locations, rather than being tied to an explicit exposure rate, i.e., 0.02 mSv h^{-1} . The inner boundary of the medium zone, $<10 \text{ mSv h}^{-1}$, is the outer boundary of the high zone. The low zone is defined outside of the outer boundary of the medium zone such that occupancy time is unrestricted for the first responders;

RDD Triage and Decontamination. Triage and decontamination strategies should be developed separately from those used for chemical and biological agents. For the more probable scenarios, expect that the victims' clothes or bodies will not be dangerously contaminated, nor will they have inhaled enough radioactivity to cause acute health effects. *This is in contrast to chemical or biological agents where the material still present on the victims could be immediately dangerous to them or others with whom they will subsequently have contact upon returning home or elsewhere.*³⁶

While medically significant levels of contamination are not expected in the general population of uninjured contaminated persons, a small subgroup of high zone evacuees or some of the injured/contaminated victims possibly will need prompt decontamination due to potential acute effects from high skin contamination, and/or medical intervention to mitigate an inhalation exposure that could lead to acute health effects, i.e., acute pneumonitis may result from an alpha emitter, or hematopoietic syndrome from ^{137}Cs :³⁶

- If possible, pre-plan to triage those who need decontamination at exits as far away from contaminated areas as practical;
- Pre-position radiological monitors at exits; and
- Assure that exit points are in areas of relatively low background, less than or equal to twice background, or at most, approximately $0.5 \text{ } \mu\text{Sv h}^{-1}$. First, separate those people who need medical consideration from those who do not (as practical).
- Assume that a person is not likely to have received a significant dose from inhalation without presenting gross external contamination at triage.

- Separate from all others those persons with upper body contamination, particularly of the shoulder, head, and hair.
- Assume that individuals with contamination only on lower portion of the body
- crossed the contaminated zone but were not exposed to the passing plume and did not inhale high airborne radioactivity concentrations. People with significant upper body contamination may require evaluation for follow-up medical treatment because they may have inhaled excess amounts of radioactive material.
- With help from the media, the HEOC can seek those persons who were outdoors in the high zone, determined by its actual radiological footprint, but were not seen at a triage station. These two subgroups of people need to be evaluated promptly; they probably do not pose an urgent medical emergency, but should be treated as a medical emergency.

RDD Personal Protective Equipment (PPE) For First Responders

because the initial plume will pass beyond the high zone in 10–15 min, most first responders will not be exposed to high airborne concentrations of particulates because they will arrive after it has passed or first encounter the plume downstream when concentrations have become diluted. Therefore, because the remaining levels of airborne radioactivity along with any additional contribution from re-suspension will be relatively low, the PPE requirements, as a minimum, are as follows:³⁶

- Uniform;
- Goggles;
- Gloves of any type; and
- Half-face air purifying respirator (APR) (most responders typically use a full-face one that affords more protection).

Supplied air respirators (Level A and B) are excessive for this level of hazard.

RDD Improvised Respiratory Protection Near The High Zone Improvised respiratory protection could be a beneficial ALARA technique provided that the public was informed about the practice before the event took place. Therefore, this issue represents a topic for discussion with the public in the planning stage rather than an emergency recommendation to be issued by the local health authorities. This countermeasure can be used to reduce inhalation during the approximately 10 to 15 min of the plume's passage.³⁶

Using protection during this period is advised because of concerns about the ability of current technology to model urban canyon environments. Based on present knowledge, it cannot be categorically ruled out that respirable particles will not be caught for a longer time in a recirculation cell by a complex urban wind pattern, although this is viewed as unlikely. For improvised respiratory protection, the following are recommended:^P

- Cover the mouth and nose with a dry cloth or handkerchief (NCRP 2001). In some cases, wet material could actually enhance the amount of inhaled particles. For example, cesium chloride is watersoluble, and so a wet cloth could concentrate the radioactivity, as well cause labored breathing; further, there may be leakage around the edges of the damp cloth;
- Remove the protection 30 min after detonation.

RDD Sheltering. Sheltering is not a critical countermeasure for an explosive scenario anywhere, although it can reduce exposure given the timing and location from ground zero. Sheltering during the passage of the plume can lower exposure, but sheltering beyond that time can entail an additional exposure when the airborne concentrations inside the buildings become higher than the outdoor concentration.³⁶

IV. MEDICAL MANAGEMENT GUIDELINES

The risks of radiation effects to treating personnel associated with a contaminated patient, if any, are commensurate with or below other risks commonly faced during the course of medical practice in most emergency departments (Linnemann, 2001). Facilities treating contaminated patients should establish guidelines regarding exposure for medical personnel.

Teratogenic effects are particularly noteworthy because there *appears to be a threshold dose below which damage does not occur* (ICRP, 2000). This dose is about 10,000 mrem (10 rem or .1 Sv), a level seldom achieved in diagnostic X-ray or nuclear medicine procedures. As an additional precaution, the suggested limit during pregnancy is 500 mrem (5 mSv). When confronted with concerns about low levels of exposure, it may be helpful to compare the dose in question with the more familiar medical exposures (Linnemann, 2001).²⁷

10 BASICS OF HEALTHCARE RESPONSE

Preparing for radiological terrorism means planning in advance so as to act appropriately. In the event of a terrorist disaster, healthcare facilities will most likely be required to carry out these “10 basics of response.”²⁷

1. Assure medical staff that when an incident combines radiation exposure with physical injury, initial actions must focus on treating the injuries and stabilizing the patient.
2. You or your hospital must be prepared to manage large numbers of frightened, concerned people who may overwhelm your treatment facility.
3. You or your hospital must have a plan for distinguishing between patients needing hospital care and those who can go to an off-site facility.
4. You or your hospital must know how to set up an area for treating radiation incident victims in an ER.
5. You or your hospital should be aware that a good way to approach decontaminating a radioactively contaminated individual is to act as if he or she had been contaminated with raw sewage.
6. You or your hospital must know how to avoid spreading radioactive contamination by using a double sheet and stretcher method for transporting contaminated patients from the ambulance to the emergency treatment area.
7. You must know how to recognize and treat a patient who has been exposed to significant levels of radiation.

8. You should recognize the radiological findings of illness/injury caused by biological or chemical terrorist agents.
9. You should know what agencies or organizations to contact in the event of a radiation emergency and how to reach them.
10. You or your hospital must have a plan to evaluate and counsel noninjured patients exposed to radiation at a location outside of the hospital.

OVERVIEW OF GENERAL MEDICAL TREATMENT FOR RADIATION INJURY

There is significant clinical experience with persons who have received large amounts of external body radiation.^{1,2} In general, medical treatment is necessary only for persons who have received external exposure with absorbed doses in excess of 1 Gy (100 rad). Antibiotics used to treat radiation-exposed patients are commonly available and, in most cases, will not be required during the initial 7 to 10 days. Many of the antibacterial agents that would be used in this setting are maintained in the Strategic National Stockpile or its vendor-managed inventory system. Other drugs that would be required include antibiotics used to treat drug-resistant organisms, antiviral medications used to treat opportunistic viral infections, and antifungal medications used to treat *Aspergillus*, candidiasis, and other fungal infections arising in patients with depressed cell-mediated immunity.³⁷

General objectives in approximate order of importance for emergency management of seriously injured and contaminated patients are as follows.³⁷

1. First aid and resuscitation
2. Medical and surgical stabilization
3. Definitive treatment of serious injuries
4. Prevention/minimization of internal contamination
5. Assessment of external contamination and decontamination
6. Treatment of other minor injuries
7. Containment of the contamination to the treatment area and prevention of contamination of other personnel
8. Minimization of external radiation to rescue and treatment personnel
9. Assessment of internal contamination
10. Treatment of internal contamination (this could be concurrent with many of the above)
11. Assessment of local radiation injuries/radiation
12. Counseling of patients about expected long-term effects and risks
13. Long-term follow-up of patients with significant whole-body irradiation or internal contamination

WHOLE-BODY RADIATION EXPOSURE

A large single exposure of penetrating γ radiation (ie, highenergy γ rays of sufficient energy to cause significant organ dose) can result in various forms of

the acute radiation syndrome (Tables IV-1, IV-2, and IV-3). The absorbed dose can initially be evaluated on the basis of symptoms and refined with laboratory studies. The presence and timing of nausea and vomiting is an excellent screening tool to detect those who require urgent medical investigation.¹⁰ Serial CBCs will identify those who have medically important radiation doses. If there is a significant decrease in lymphocytes in the first 6 to 48 hours, prolonged and intense medical treatment will likely be required (Table IV-4).³⁷

At dose levels greater than 30 Gy (3,000 rad) of whole-body penetrating radiation, the cardiovascular/central nervous system syndrome occurs primarily as a result of hypotension and cerebral edema. There is almost immediate nausea, vomiting, prostration, hypotension, ataxia, and convulsions. These casualties should receive palliative treatment only because death invariably occurs within several days. Events that have produced this dose level are extremely rare, having occurred in only a handful of accident victims worldwide.^N The gastrointestinal syndrome occurs from acute whole-body doses of approximately 6 to 20 Gy (600 to 2,000 rad), primarily because of death of intestinal mucosal stem cells. In this syndrome, there is prompt onset of nausea, vomiting, and diarrhea. There is a latent period of approximately 1 week and then recurrence of gastrointestinal symptoms, sepsis, electrolyte imbalance, and ultimately death.³⁷

The hematopoietic syndrome occurs from acute whole-body doses of approximately 2 to 10 Gy (200 to 1,000 rad) as a result of bone marrow depression. After prodromal symptoms, there is a latent period of 2 to 3 weeks during which the patient may feel well. During this time, arrangements for medical care at an appropriate center should be coordinated. Lymphocyte depression can occur within 48 hours and is a useful indicator of dose. Maximal bone marrow depression with leukopenia and thrombocytopenia occurs several weeks after exposure; hemorrhage and infection can be major clinical problems.^N The correct diagnosis of potential radiation injury is made approximately 85% of the time by a thorough medical history. However, the recent history of radiation medicine shows many cases of delayed diagnosis. In an analysis of 4 major radiation accidents involving lost sources (Mit Halfa, Egypt [May 2000]; Bangkok, Thailand [February 2000]; Tammiku, Estonia [October 1994]; and Goiania, Brazil [September 1987]), the average time from beginning of the accident until definitive diagnosis averaged approximately 22 days. Other accidents, such as the nuclear criticality accident in Tokaimura, Japan, in September 1999, were recognized immediately because of their occurrence in industrial settings with known radiation hazards.³⁷

If the patient is aware, radioactive source exposure, description, time of onset of symptoms, and symptom severity should be documented. An early, baseline CBC with differential should be obtained and repeated every 4 to 6 hours to monitor for declines in the lymphocyte and neutrophil count.³⁷

In addition, blood may be obtained after 24 hours for chromosomal aberration biodosimetry. After medical stabilization, patients should be assessed for radiation injury on the basis of dose, isotope, and presence of internal contamination. Rapid-sort, automated chromosome biodosimetry and assessment of clinical characteristics such as the time to emesis post event and lymphocyte depletion kinetics estimate radiation dose to a patient involved in a mass casualty incident. Time to emesis, measured from the time of irradiation, decreases monotonically with increasing dose. For time to emesis less than 4 hours, the effective whole-body dose is likely to be at least 3.5 Gy. If time to emesis is less than 1 hour, the whole-body dose probably exceeds 6.5 Gy, and a very complicated and likely fatal medical course may be expected.³⁷

Lymphocyte depletion follows first-order kinetics after high-level g and criticality incidents. An estimation of patient radiation dose may be obtained from the medical history, serial lymphocyte counts, and time to emesis using algorithms from the Armed Forces Radiobiology Research Institute's (AFRRI) free Biological Assessment.³⁷

LOCALIZED EXPOSURE

Localized, deep exposure to radiation is caused by direct handling of highly radioactive sources. The patient often survives even if the absorbed doses are very high. Because the dose rate drops rapidly as the distance from the radioactive sources increases, systemic manifestations are not as severe as the local injury. The signs of a radiation burn are similar to those of a thermal burn: erythema and desquamation or blistering. However, the signs of a radiation burn appear after a period of days (Table IV. 1).³⁸

Vascular insufficiency can develop several months or years later, causing ulceration or necrosis of tissues that had previously healed. Treatment of localized radiation injuries usually involves prophylaxis against infection, control of pain, and vasodilator therapy; in some cases, plastic surgery, grafting, or amputation is required. The extent of penetration of the radiation is an important factor in the outcome of local injury. With heavy radioactive fallout, beta rays cause superficial skin burns, particularly on portions of the body not covered by clothing.³⁸

Table IV-1. Skin Changes After A Single Acute Localized Exposure³⁸

Absorbed Dose	Change
3–4 Gy	Epilation in 2–3 weeks
10–15 Gy	Threshold for erythema; appears 18–20 days after exposure at lower doses; may appear within a few hours at higher doses
20 Gy	Moist desquamation, possible ulceration
25 Gy	Ulceration with slow healing

30–50 Gy	Blistering, necrosis at 3 wk
100 Gy	Blistering, necrosis at 1–2 wk

PATIENT SAMPLING AND MONITORING

Biological Dosimetry Individual biodosimetry is essential for predicting the clinical severity, treatment, and survivability of exposed individuals and triaging those with minimal or no exposure. The 3 most useful elements for calculating the exposure dose are *time to onset of vomiting*, *lymphocyte depletion kinetics*, and the *presence of chromosome dicentric*s. A radiation casualty management software program, the Bio Biological Assessment Tool, is available at the AFRRRI website. This tool was developed in collaboration with REAC/TS and others to facilitate medical recording and estimation of individual dose.³²

In addition, the International Atomic Energy Agency has developed generic guidelines for recording clinical signs and symptoms for victims of a radiation incident. Using a grading system for the severity of clinical signs and symptoms, the Medical Treatment Protocols team has also developed a quantitative system to assess individual biological response to radiation exposure when results of chromosomal analysis are not yet available. Prodromal signs and symptoms must be recorded throughout the course of medical management after a radiation exposure. Body location of radioactivity and thermal and traumatic injuries, and the degree of erythema, must be recorded on medical cards or flow charts that document signs and symptoms as a function of time after exposure. Dose estimates derived from the use of personnel dosimeters (if available) or other radiation monitoring devices must be recorded as well. These data may then be entered into the Biological Assessment Tool (or similar recording devices) at set triage stations so that an exposure dose can be estimated and the patient can be triaged accordingly.³²

Bioassay tests may be required for detecting internally deposited radionuclides resulting from contamination events. Bioassay sampling can consist of urinalysis, fecal sampling, and sampling of other body tissues or excreta. Nasal smears are used to obtain qualitative information about inhalation of radionuclides. Nasal smears can confirm that an inhalation exposure occurred, but cannot demonstrate that one did not occur. Gamma spectroscopy can be used to estimate quantities of radionuclide ingestion or inhalation. These can be lung counters, thyroid counters, and whole body counters. In-vivo measurements can be performed some time after an event. In some cases it may be required to send an individual to a location with the appropriate counter, or a mobile counter can be relocated temporarily at the site after an event. Commercial mobile in-vivo counting systems are routinely

used at commercial facilities periodically when demand for body counting is at a peak. These could be transported to an event site within 2 days if not less.³⁰

Nasal Smears If it is suspected that contamination may have entered a body opening or wound, swabs (Q-tips®) may be used to collect surface material. If they are available, have medical personnel perform the sample collection using the swabs to avoid injuring the victim. These swabs may then be checked with a radiation detector.³²

Biological Monitoring Events involving significant dose exposure may require taking blood samples to determine white blood cell count and performing chromosome aberration analysis. Most medical laboratories, medical clinics, or medical universities can perform this. A 24-hour emergency response program of the DOE at the Oak Ridge Institute for Science and Education (ORISE), Radiation Emergency Assistance Center/Training Site REAC/TS trains, consults, or assists in the response to all types of radiation accidents or incidents. The Center's specially trained team of physicians, nurses, health physicists, radiobiologists, and emergency coordinators is prepared around-the-clock to provide assistance on either the local, national, or international level.³²

Gamma Contamination Monitoring Portal monitors would be the preferable method of detecting gamma emitters. Examples of this type of contamination include Cs-137, Co-60, Co-57, and Ir-192.³²

Iodine Contamination Monitoring Monitoring will include thyroid counting with NaI detector. If large quantities of iodine are discovered in the body, it can be blocked from uptake using potassium iodide (KI). A person's sensitivity to iodine must be considered to determine the trade-off between the potential dose averted vs. risk from the iodine administration. Guidance is provided in "Guidance Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies"ⁱ and Potassium Iodide (KI) Health Physics Society Fact Sheetⁱⁱ for determining when administration of KI is warranted. If possible, it is better to administer KI before the event, rather than after, although significant reduction in thyroid dose can be achieved by administering it immediately after the exposure occurs.³²

Predicted Thyroid exposure in Rad to warrant use of Potassium Iodide
 Adults over 40 years ≥ 500
 Adults over 18 through 40 years ≥ 10
 Pregnant or lactating women and children less than 18 years ≥ 5

Beta-gamma contamination monitoring Generally, hand-held beta-gamma probes will be used. Portal monitors (or whole body contamination monitors) may be used, if sensitive enough depending on the level of photon radiation associated with the radionuclide.³²

Alpha contamination monitoring Hand-held alpha instruments will be used to detect contamination at the release limit. If radionuclides other than alpha emitters are present, they may be used as an indicator for the alpha contamination, assuming the ratio of alpha/beta is well characterized and known.³²

Tritium contamination monitoring If the release event takes place outdoors, the dose from a tritium release would not be expected to be significant because most of the large sources of tritium are in gaseous form which is readily dispersed to the atmosphere and rises because the gas is lighter than air. Water vapor tritium intake can result in doses, but, because of the generally lower source term, would result in lower doses. Urinalysis can easily detect the magnitude of any intakes. Limiting eating and drinking to known suspect supplies of food and water should be adequate to prevent future intakes.³²

Inhalation Concerns A major consideration in decon operations is the re-suspension of radioactive contamination. This can occur when decon personnel remove clothing from personnel going through the decon process. It can also occur when people or equipment move through a contaminated area and disturb the dirt and dust, causing the smaller particles to be suspended in the air. Improperly masked or unmasked personnel can inhale this contaminated radiological material and, over time, develop health-related problems. Where resources permit, trained personnel should take nasal swabs of victims to determine who has inhaled radioactive material. Responders should also conduct nasal swabs on themselves. If it is believed that improperly masked or unmasked personnel were exposed to re-suspended radioactive material, a swab of the nasal cavity should be conducted to confirm or exclude the presence of contamination. Personnel testing positive should be referred to a doctor for further disposition and treatment.³²

Lymphocyte Count. The rate of decline and nadir of the absolute lymphocyte count over the initial 12 hours to 7 days after exposure is a function of cumulative dose. Lymphocyte depletion kinetics predict dose assessment for a photon-equivalent dose range between 1 and 10 Gy with an exposure resolution of approximately 2 Gy. Ideally, a complete blood cell count with leukocyte differential should be obtained immediately after exposure, 3 times per day for the next 2 to 3 days, and then twice per day for the following 3 to 6 days. However, this will require that deployable hematology laboratory capabilities be established and exercised for potential mass-casualty scenarios. It is recommended that 6 (and a minimum of 3) complete blood counts with differential be obtained within the initial 4 days after exposure to calculate a slope for lymphocyte decline that can be used to estimate exposure dose. Complete blood counts with differential should then be

obtained weekly or twice weekly until a nadir in neutrophil count is defined. The chromosome-aberration cytogenetic bioassay, primarily the lymphocyte dicentric assay introduced by Bender and Gooch (48), remains the gold standard for biodosimetry.³²

Table IV-2 Acute Radiation Syndrome (ARS), or suspected ARS examination and test suggestions.³²

Initial examinations: (Frequency: days 1, 2, and 3 post-exposure, then 2 or 3 times a week depending on the clinical situation)					
General physical examination	Past medical history	Complaints Signs and symptoms	Presence of skin burns	Presence of GI disorders	
Tests to perform daily:					
CBC, blood count	Weight test	Guiaic (blood in excreta)	Attention to iv and po input and urinary and GI output		
Tests to perform on days 1, 2, and 3 post-exposure, and 2 or 3 times a week depending on the clinical situation					
Laboratory Tests:					
Hematology Blood cell profile	Blood Smear	Electrolyte profile	Chemistry profile	Thyroid function studies	Biochemistry
WBC RBC HGB HCT MCV MCH MCHC RDW-SD PLT	Neutrophil Lymphocyte Monocyte Eosinophil Basophil	Na K Cl CO2	BUN Creatinine Glucose Uric acid Cholesterol Triglycerides Calcium Phosphorus Total protein Albumin Globulins Total bilirubin Alk phos ALT / SGPT AST / SGOT LD	T4-RIA	PT - Prothrombine time* PTT - Partial thromboplastin time* Clotting time * Bone marrow aspiration * Chromosome (FISH)
* if clinically applicable					
Ophthalmology Slit lamp (6 months post exposure)					

CONTROL OF INFECTIONS.

A variety of measures has been advocated to reduce infections in the irradiated patient. These measures include meticulous hygiene of skin and orifices, aseptic skin punctures, reverse isolation, and prophylactic ad-ministration of

immunoglobulin G. Difficulties associated with the strict maintenance of reverse isolation procedures are obvious. Laminar airflow rooms are in limited supply, constant surveillance is required for nosocomial infectious agents in plumbing fixtures and ice machines, and food must be free of gram-negative bacteria (no raw fruit, vegetables, or salad). The best result that might be achieved by these methods is a reduction in the appearance of new infections. Meanwhile, endogenous reinfection would be little affected unless antibiotics to eliminate opportunistic pathogens from the gut are effectively used. Although measures to control infection are prudent, their efficacy has not been clearly shown. Life-threatening infections remain a complication in the management of radiation casualties.³⁸

Maximum doses of two or three antibiotics of different classes should be infused empirically when specific signs of bacterial infection occur. These signs include the appearance of a sudden fever spike, usually in the presence of a depressed leukocyte count (that is, granulocytes fewer than 500/mm). Prophylactic antibiotic treatment has given good results when used perioperatively in patients who have penetrating abdominal wounds. The use of poorly absorbed oral antibiotics that selectively decontaminate the gut may be indicated as a preventive measure in patients known to have been exposed to moderate or high radiation doses. Even commonly used and widely available antibiotics (penicillins, streptomycins, and sulfas) may be useful with mass casualties, because sensitive and otherwise- noninvasive organisms usually become prominent pathogens in immuno-suppressed radiation casualties. Antifungal and antiviral agents are indicated when specific signs of these infections occur.^{32, 33}

Antibiotics may rapidly become scarce in a mass-casualty radiation disaster and should be allocated to the victims most likely to survive. Such patients include (a) those with minimal injuries and evidence of localized infection, (b) those who require only one surgical procedure, and (c) those with contaminated wounds who have received lower doses of radiation.^{32, 33}

ANTIEMETICS AND ANTIDIARRHEALS.

The phenothiazine class of antiemetics, when used in the high doses needed to relieve a radiation victim's nausea and vomiting, has an unacceptably high incidence of extrapyramidal neurological side effects. Since the currently available antiemetic agents are of limited use, intense re-search efforts have been directed to finding new agents. Promising results have been obtained with the use of serotonin (5-HT₃) blocking agents. This class of drugs significantly reduces radiation-induced emesis in the ferret, nonhuman primate, and human. However, some of the drugs may result in nausea. Results of clinical trials of these relatively nontoxic agents are pending, as is their approval as agents potentially useful in the field by NATO forces. The goal in the use of any effective antiemetic is threefold: (a) to enhance patient comfort without drug side effects, (b) to reduce the risk of aspiration pneumonia, and (c) to conserve body fluid and electrolytes. It may be possible to prevent emesis by administering serotonin

antagonists prophylactically or immediately after expo-sure. Diarrhea from radiation damage to the gut may be controlled in part by a restricted-fiber diet and in part by medication. Drugs such as diphenoxylate HCl, codeine, or atropine have been advocated. If these are ineffective and the damage is localized to the large bowel, hydrocortisone enemas may help. The late compli- cation of bowel stricture from local radiation damage is managed surgically.³³

FLUIDS AND ELECTROLYTES.

While adequate supplies of intravenous fluids are not likely to be available in a situation involving mass radiation casualties, the survival of patients with milder cases of fluid and electrolyte loss may be enhanced by replacement therapy. Careful measurement of the volume of losses will serve two purposes: (a) patients with severe degrees of fluid loss can be categorized as expectant, and (b) the proper volume of replacement can be given to patients who are capable of surviving. Measurement of the relative volumes of vomitus and diarrhea will help guide the fluid replacement. Those with more vomiting than diarrhea will suffer the greater loss of chlorides and may develop alkalosis, while those with secretory, cholera-like diarrhea may develop hypokalemia and hyponatremia with total-body salt depletion. The collection and measurement of excretions, including urine, serve another purpose: with the proper collection of serial specimens and access to radioanalysis equipment, estimates of internal radionuclide contamination can be made by measuring the radioactivity of the samples. In the event of combined-burn injury involving more than 10% of the body surface, crystalloid infusions are just as satisfactory as colloid, but a higher volume of infusate may be necessary.³³

Table IV-3. Findings of the prodromal phase of acute radiation syndrome.³³

ARS Degree and the Approximate Dose of Acute WBE, Gy					
Symptoms and Medical Response	Mild (1-2 Gy)	Moderate (2-4 Gy)	Severe (4-6 Gy)	Very Severe (6-8 Gy)	Lethal (>8 Gy)
Vomiting					
Onset	2 hr after exposure or Later	1-2 hr after exposure	Earlier than 1 hr after exposure	Earlier than 30 min after exposure	Earlier than 10 min after exposure
Incidence	10-50%	70-90%	100%	100%	100%
Diarrhea					
Onset	None	None	Mild	Heavy	Heavy
Incidence			<10%	>10%	almost 100%
Headache					
Onset	Slight	Mild	Moderate	Severe	Severe
Incidence			50%	80%	80-90%

Consciousness	Unaffected	Unaffected	Unaffected	May be altered	Unconsciousness may last seconds or minutes
Onset					Seconds to minutes
Incidence					>50 Gy 100%
Body Temperature	Normal	Increased	Fever	High Fever	High Fever
Onset		1-3 hr	1-2 hr	1 hr	1 hr
Incidence		10-80%	80-100%	100%	100%
Medical Response	Outpatient observation	Observation in general hospital Treatment in specialized hospital	Treatment in specialized hospital	Treatment in specialized hospital	Palliative treatment (Symptomatic only)
ARS, Acute radiation syndrome; WBE, whole-body exposure.					
* With appropriate supportive and marrow resuscitative therapy, individuals may survive for 6 to 12 months with whole-body doses as high as 12 Gy. Adapted from International Atomic Energy Agency, Diagnosis and Treatment of Radiation Injuries, Safety Report Series No. 2. Vienna; 1998.29					

Table IV-4. Findings of the critical phase of acute radiation syndrome.³⁷

Degree of ARS and Approximate Dose of Acute Whole-Body Exposure, Gy					
	Mild (1-2 Gy)	Moderate (2-4 Gy)	Severe (4-6 Gy)	Very Severe (6-8 Gy)	Lethal (>8 Gy)
Onset of Signs	30 days	18-28 days	8-18 days	<7 days	<3 days
Lymphosites	0.8-1.5 G/L	0.5-0.8G/L	0.3-0.5G/L	0.1-0.3G/L	0.0-0.1G/L
Platelets	60-100G/L	30-60G/L	25-35G/L	15-25G/L	>20G/L
Clinical Manifestations	Fatigue, Weakness	Fever, Infections, Bleeding, Weakness, Epilation	High Fever, Infections, Bleeding, Weakness, Epilation	High Fever, diarrhea, vomiting, dizziness and disorientation, hypotension	High Fever, Diarrhea, unconsciousness
Lethality	0%	0-50%	20-70%	50-100%	100%
Onset		6-8 Weeks	4-8 weeks	1-2 Weeks	1-2 Weeks
Medical Response	Prophylactic	Special prophylactic, Treatment from days 14-20 Isolation from days 10-20	Special prophylactic, Treatment from days 7-10, Isolation from beginning	Special treatment from first day, Isolation from the beginning	Symptomatic treatment only

GL, international parlance (SI units) for concentration and refers to Giga per Liter/or 1×10^9 items per liter.
Adapted from International Atomic Energy Agency, Diagnosis and Treatment of Radiation Injuries, Safety Report Series No. 2. Vienna; 1998.29
*One Gray=100 rad.
yIn very severe cases, with a dose >50 Gy, death precedes cytopenia (production of one or more blood cell types ceases or is greatly reduced).
Epilation = Hair loss.

SUPPORTIVE CARE

Supportive care includes the administration of antimicrobial agents, antiemetic agents, antidiarrheal agents, fluids, electrolytes, analgesic agents, and topical burn creams. Experimental work performed more than 2 decades ago demonstrated the efficacy of supportive care, including the use of systemic antibiotics directed at gram-negative bacteria and transfusion with fresh, irradiated platelets. Careful attention must be given to early fluid resuscitation of patients with significant burns, hypovolemia, hypotension, and multiorgan failure.³²

EXPECTANT CARE

Expectant care (treatment for comfort with psychosocial support) is recommended for patients who develop multiorgan failure within hours after exposure, as their radiation dose will have been high (>10 Gy). Resources permitting, routine critical care therapy should be provided to patients who develop multiorgan failure several days to weeks after exposure because their dose will have been in the moderate range. Therapy includes endotracheal intubation; administration of anticonvulsant agents; and the judicious use of parenteral analgesic agents, anxiolytic agents, and sedatives, as needed.³²

V. THE COMBINED-INJURY PATIENT

RADIATION EMERGENCY AREA The patient who is both contaminated and injured must be treated in the emergency department's Radiation Emergency Treatment Area where the patient can receive adequate medical care while the contamination is controlled. The Radiation Emergency Area is not necessarily a fixed location in the emergency department. It can be set up anywhere in the hospital, e.g., in the OR. It must always have an entrance, a treatment area, a buffer zone and an exit. The entire complex *must* be controlled. The flow of personnel, equipment and supplies is in one direction, from the clean part of the hospital into the controlled area. NOTHING and NO ONE leaves this area until properly surveyed for contamination. This includes blood samples, X-rays, etc.. Contamination that is not visible to the naked eye – dirt, liquid, etc. – will not have enough radioactivity to cause early or visible radiation injury to the patient or attendant, and late effects are likely to be negligible. An unhurried approach to decontamination also is influenced by the fact that radiation intensity decreases with the passage of time (Linnemann, 2001). With a survey meter, levels of contamination are measured in the following units:²⁷

- cpm cpm Counts per minute
- mrad/hr mSv/hr millirad (milliSievert) per hour
- rad/hr Sv/hr rad (Sievert) per hour

The units as listed indicate an increasing amount of radiation exposure. Levels in the cpm range and millirad range are associated with a low level risk to the medical personnel. Only in the rad/hr (Sv/hr) range would it be necessary to institute more stringent radiation protective procedures in nonlife saving situations. These include:²⁷

- minimizing time spent near the patient,
- immediate gross decontamination of the patient by removing all clothing and wash down of the patient with copious amounts of water or saline in case of wounds.

TRIAGE OF THE COMBINED-INJURY PATIENT

Priorities in handling patients of conventional trauma are modified in cases of concurrent radiation injury. Triage priority is based on the conventional injury as well as the degree of radiation suffered by the combined-injury victim (Table V-1). All patients exposed to more than 4.5 Gy are in the expectant category, as are those with exposure of 1.5-4.5 Gy who cannot be given care immediately. If exposure was less than 1.5 Gy, the nature of the conventional injury will dictate the treatment priority. Casualties who receive radiation exposure alone over a wide range of doses will need little if any treatment initially.³³

Since an estimate of the exposure dose in the early phases of radiation casualty triage will be almost impossible, a more practical triage scheme, based on symptoms of unlikely, probable, or severe radiation exposure, will be useful (Table V-2). In the event of combined injuries, symptoms of probable or severe exposure may be confused with symptoms associated with conventional injury. In giving the benefit of the doubt to such patients, those with injuries treatable on an immediate basis should receive prompt attention. However, if radiation exposure does account for the observed symptoms, the patient in the conventional categories of immediate (Table V-3) or delayed (Table V-1) may actually be expectant. Even with severe symptoms of radiation exposure, patients with minimal traumatic injury may be capable of survival if evacuated for observation and advanced medical management. However, if transportation resources are limited, disposition of the minimally injured but heavily exposed patient should coincide with that of the casualty in the expectant category. Patients in the delayed category with probable radiation symptoms are expectant, unless adequate tertiary-care facilities are readily available. Regardless of the triage scheme used, it is probable that a number of combined-injury patients in the expectant category will receive treatment for more immediate and delayed conventional injuries.³³

Table V-1 Priorities in when radiation doses are known³³

COMBINED-INJURY TRIAGE			
Conventional Triage Categories if Injuries Are Only Trauma	Changes in Expected Triage Category Following Whole-Body Radiation Dose		
	No Radiation Exists	1.5 Gy	1.5 to 4.5 Gy
T 1	T 1	T 1	T 4
T 2	T 2	T 4	T 4
T 3	T 3	T 4	T 4
T 4	T 4	T 4	T 4

It will be difficult to assess the radiation doses of persons who have been injured in a mass-casualty disaster. Thus, a system has been devised to identify radiation exposure based on the symptoms of “unlikely,” “probable,” or “severe” radiation injury (Table III-2). These symptoms are nonspecific, and permit only the cursory screening of a large number of cases.¹

Table V-2 Estimation of possible radiation injury based on symptoms.³³

ESTIMATION OF POSSIBLE RADIATION INJURY BASED ON SYMPTOMS			
Nausea	-	++	+++
Vomiting	-	+	+++
Diarrhea	-	+	± to +++
Hypothermia	-	+	± to +++
Erythema	-	-	- to ++

Hypotension	-	-	+ to ++		
CNS Dysfunction	-	-	- to ++		
Table III-3. Priorities in combined injury triage when radiation injury is possible. ¹					
PRIORITIES IN COMBINED INJURY TRIAGE WHEN RADIATION INJURY IS POSSIBLE					
Conventional Triage Categories if Injuries Are Only Trauma	Changes in Expected Triage Category Following Possibility of Radiation Injury				
No Radiation Exists	Unlikely	Probable	Confirmed		
			Minimum	Moderate	Severe
T 3	T 3	T 1	T 3	T 3	T 3
T 2	T 2	T 2/T 4	T 3	T 4	T 4
T 1	T 1	T 3/T 4	T 3	T 4	T 4
T 4	T 4	T 4	T 4	T 4	T 4

Concerns in the Treatment of the Combined-Injury Patient Once an airway, proper ventilation, and circulatory stability have been established, definitive care should be planned for the casualty who can survive. Treatment planning is based on the competent handling of conventional injury and the anticipation of predictable sequelae of radiation injury. In the following discussion, early placement of a peripheral intravenous catheter for infusion of adequate quantities of fluids and blood components is assumed. The use of central venous lines in protected sites for long-term infusions is also discussed.³³

The decision to apply any of these measures to the combined-injury patient will be a difficult one, and will have to be based on the availability of resources and the projected number of casualties. The prognosis for combined injury is markedly worse than for either traumatic or radiation injury alone. Patients with moderate or severe conventional injuries who arrive at tertiary centers that are capable of handling combined injuries will probably receive the maximum available care, unless they have received obviously massive doses of radiation (over 8 or 9 Gy). It will be hard to justify the decision to continue therapeutic interventions in a trauma patient whose dose of radiation is eventually determined to exceed 4 Gy. Continuing advanced life-support measures will not be in the best interests of a patient who will most likely suffer a protracted, terminal illness. Nor will less-injured patients benefit if their access to hospital resources is limited because of the excessive allocation to hopeless cases. On the other hand, the military organization should attempt to assure that the psychological support of casualties in the expectant category are augmented as much as possible by nonmedical personnel.¹

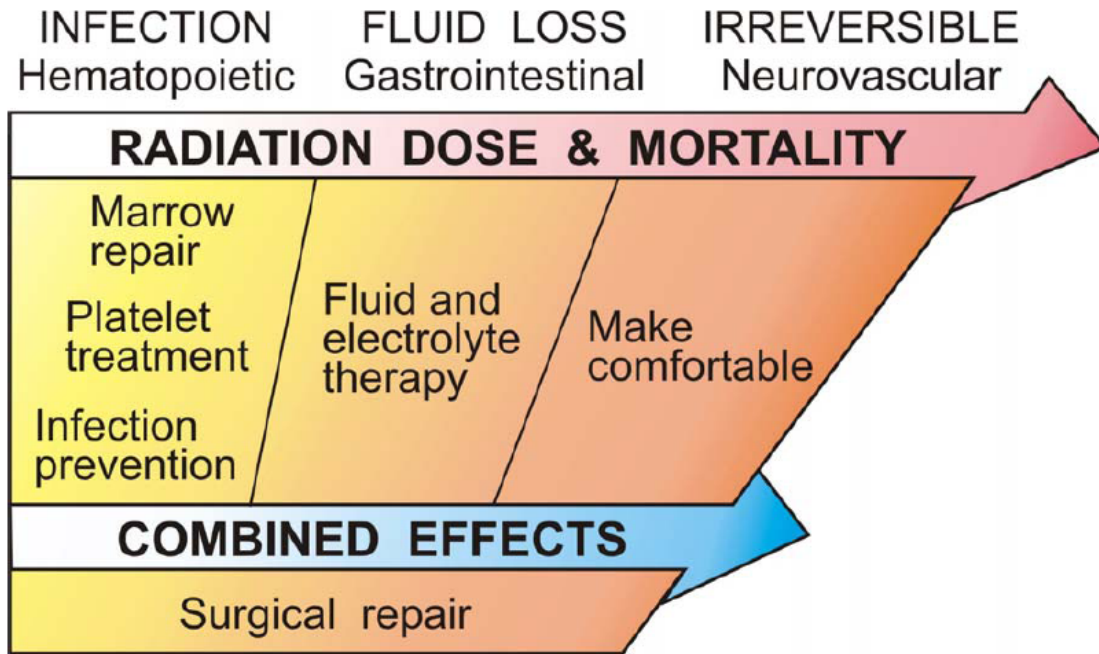


Figure IV.1 Combined Effects of Radiation and blast injuries.³³

FLUIDS AND ELECTROLYTES

While adequate supplies of intravenous fluids are not likely to be available in a situation involving mass radiation casualties, the survival of patients with milder cases of fluid and electrolyte loss may be enhanced by replacement therapy. Careful measurement of the volume of losses will serve two purposes: (a) patients with severe degrees of fluid loss can be categorized as expectant, and (b) the proper volume of replacement can be given to patients who are capable of surviving. Measurement of the relative volumes of vomitus and diarrhea will help guide the fluid replacement. Those with more vomiting than diarrhea will suffer the greater loss of chlorides and may develop alkalosis, while those with secretory, cholera-like diarrhea may develop hypokalemia and hyponatremia with total-body salt depletion. The collection and measurement of excretions, including urine, serve another purpose: with the proper collection of serial specimens and access to radioanalysis equipment, estimates of internal radionuclide contamination can be made by measuring the radioactivity of the samples. In the event of combined-burn injury involving more than 10% of the body surface, crystalloid infusions are just as satisfactory as colloid, but a higher volume of infusate may be necessary.³³

Placement of central venous catheters made of silicone elastomer (such as the Hickman or Broviac type) should be considered a minor surgical procedure and be accomplished within the first 36 hours, if needed. Vascular obstructions and exotic infections increasingly complicate the use of these lines in immunocompromised patients and so they should be limited to the critically injured patients

who need them most. However, a long-term illness following serious radiation injury will dictate that long-term venous access be maintained. The probability of wound-healing disturbances and the chronicity of phlebotoxic intra-venous therapy involved in the care and treatment of any critically ill patient make central venous access preferable to peripheral intravenous access.³³

Using peripheral lines in the radiation casualty has further disadvantages:³³

- placement is difficult if hemostasis is compromised and local hemorrhage develops,
- placement is restricted to percutaneous insertion after 36 hours, even if a venous cutdown is otherwise desirable,
- the lines are unsuitable for infusion of hyperosmolar solutions, and the lines are at greater risk of becoming infected at the catheter tip if used longer than 72 hours. Long-term use of the percutaneous subclavian cannula made of polyethylene or polyvinyl chloride is contraindicated because of the high rates of infection, vascular occlusion, and thrombogenicity associated with these materials.

SPECIFIC TREATMENT CONCERNS

Control of Infections. A variety of measures has been advocated to reduce infections in the irradiated patient. These measures include meticulous hygiene of skin and orifices, aseptic skin punctures, reverse isolation, and prophylactic administration of immunoglobulin G. Difficulties associated with the strict maintenance of reverse isolation procedures are obvious. Laminar airflow rooms are in limited supply, constant surveillance is required for nosocomial infectious agents in plumbing fixtures and ice machines, and food must be free of gram-negative bacteria (no raw fruit, vegetables, or salad). The best result that might be achieved by these methods is a reduction in the appearance of new infections. Meanwhile, endogenous reinfection would be little affected unless antibiotics to eliminate opportunistic pathogens from the gut are effectively used. Although measures to control infection are prudent, their efficacy has not been clearly shown. Life-threatening infections remain a complication in the management of radiation casualties.³³

Maximum doses of two or three antibiotics of different classes should be infused empirically when specific signs of bacterial infection occur. These signs include the appearance of a sudden fever spike, usually in the presence of a depressed leukocyte count (that is, granulocytes fewer than 500/mm). Prophylactic anti-biotic treatment has given good results when used perioperatively in patients who have penetrating abdominal wounds. The use of poorly absorbed oral antibiotics that selectively decontaminate the gut may be indicated as a preventive measure in patients known to have been exposed to moderate or high radiation doses. Even commonly used and widely available antibiotics (penicillins, streptomycins, and sulfas) may be useful with mass casualties, because sensitive and otherwise-noninvasive

organisms usually become prominent pathogens in immuno-suppressed radiation casualties. Antifungal and antiviral agents are indicated when specific signs of these infections occur.³³

Antibiotics may rapidly become scarce in a mass-casualty radiation disaster and should be allocated to the victims most likely to survive. Such patients include (a) those with minimal injuries and evidence of localized infection, (b) those who require only one surgical procedure, and (c) those with contaminated wounds who have received lower doses of radiation.³³

Antiemetics and Antidiarrheals. The phenothiazine class of antiemetics, when used in the high doses needed to relieve a radiation victim's nausea and vomiting, has an unacceptably high incidence of extrapyramidal neurological side effects. Since the currently available antiemetic agents are of limited use, intense re-search efforts have been directed to finding new agents. Promising results have been obtained with the use of serotonin (5-HT₃) blocking agents. This class of drugs significantly reduces radiation-induced emesis in the ferret, nonhuman primate, and human. However, some of the drugs may result in nausea. Results of clinical trials of these relatively nontoxic agents are pending, as is their approval as agents potentially useful in the field by NATO forces. The goal in the use of any effective antiemetic is threefold:³³

- to enhance patient comfort without drug side effects,
- to reduce the risk of aspiration pneumonia, and
- to conserve body fluid and electrolytes.

It may be possible to prevent emesis by administering serotonin antagonists prophylactically or immediately after expo-sure. Diarrhea from radiation damage to the gut may be controlled in part by a restricted-fiber diet and in part by medication. Drugs such as diphenoxylate HCl, codeine, or atropine have been advocated. If these are ineffective and the damage is localized to the large bowel, hydrocortisone enemas may help. The late complication of bowel stricture from local radiation damage is managed surgically.³³

Surgery. Since exposure to doses of less than 5 Gy is of no immediate threat to health, conventional injury that is surgically remediable deserves priority treatment. Ideally, surgery should be initiated as soon as possible, or within 36 hours of radiation exposure, and be completed before 48 hours. Surgery after this time is contraindicated for at least 6 weeks, or until there is evidence that immunocompetence has returned and that incised tissue is able to revascularize. Clearly, the best candidate for surgery is the patient who requires only one procedure with no surgical revision. Patients who have been exposed to more than 1.5 Gy, who have extensive injuries, and who need multiple procedures and reconstructive surgery are classified as

expectant. However, patients who have suffered severe conventional injury, who have had successful wound closure, and who then received radiation may actually be more radioresistant and better able to survive.³³

Decontamination of the radiation casualty should include prompt surgical debridement, if needed, and washing of the surgical area with mild antiseptic soaps. The skin should be cleansed before surgery to adequately reduce any radioactivity in the area of the incision. An important secondary concern is to cleanse crevice areas (nails, ears, and skinfolds) and orifices (particularly mouth and anogenital regions). To avoid abrading the skin, washing should be done gently with mild soaps and hair should be clipper-cut instead of shaved. These procedures will eliminate at least 95% of a patient's surface contamination with isotopes.³³

Anesthesia and Pain Control. In controlled trials with animals, the induction and recovery from anesthesia for irradiated subjects do not differ from those for nonirradiated subjects. However, anecdotal experience in humans has suggested that the times of induction and recovery from anesthesia may be prolonged. In irradiated animals and humans, there is a clear resistance to the effects of analgesics. However, care should be exercised to avoid overtreatment with sedative narcotics and anesthetics.³³

In a local high-dose radiation injury (over 40 Gy) to an extremity, prompt amputation gives the patient the greatest pain relief and makes the most efficient use of resources. The use of nonsteroidal anti-inflammatory drugs and thrombolytic agents, as well as topical corticosteroids, has been claimed to delay the appearance of dermal necrosis and to lessen the pain of local skin damage. However, topical corticosteroids are contraindicated in thermal burn injuries.³³

Blood Component Therapy. Impaired hemostasis after radiation injury is best related to the decline in platelet numbers that occurs several weeks after exposure. After protracted lower-dose irradiation, the decline in platelets may take more than 2 weeks. In the interim, autologous platelets can be harvested, cryopreserved, and stored for later reinfusion. This procedure was used successfully to aid the victims of the Chernobyl reactor accident. If bleeding develops, patients with reduced numbers of platelets secondary to marrow suppression benefit from platelet transfusion even if the count is greater than 20,000/mm. However, prophylactic platelet transfusions are indicated on a regular basis if the count falls below 20,000/mm, even in the absence of bleeding.³³

Platelets can be collected either by harvesting the platelet-enriched plasma obtained by centrifugation of fresh units of whole blood, or by using plateletpheresis. Although pheresis technology is complicated and expensive, each pheresis platelet concentrate provides the equivalent of platelets from five to

eight whole-blood donations. Thus, a single pheresis unit is the usual transfusion dose and can be obtained in a single cost-effective procedure.³³

Anemia develops rapidly in the critically injured radiation casualty. Maintenance of perfusion pressure and oxygen delivery to injured areas, better wound healing, and an enhanced sense of well-being will depend on preventing anemia through red-cell transfusions. As with patients suffering thermal burns alone, patients with radiation skin burns and those with combined injuries require more red-cell transfusions. A recall system is essential for the large number of healthy blood donors needed to keep up with the demand for red cells for mass casualties.³³

Erythrocytes may be stored for up to 10 years using modern cryopreservation techniques. Critical government and military leaders should stockpile autologous blood for use in case of wartime emergency.³³

In the fight against infections, fresh heterologous granulocyte infusions, bone-marrow transplants, and even the use of recombinant leukocyte stimulatory factors, such as granulocytemacrophage colony-stimulating factor (GM-CSF), have been advocated. Adequately controlled clinical investigations are needed to demonstrate the effectiveness and safety of these three therapies. Unfortunately, such a study was not performed during the clinical use of GM-CSF in the 1987 radiation disaster in Brazil. Further research is needed if the preservation of granulocytes for autologous transfusion is to be made practical. A protocol has yet to be developed for the rational and balanced use of the many humoral hema-topoietic stimulatory factors and the timing of their administration. The disappointing results from attempts to use conventional bone-marrow transplants in radiation victims have obviated the use of this procedure in the treatment of mass radiation casualties.³³

Nutritional Support. In combined-injury patients and in nonirradiated critically ill patients, heightened catabolic stress and impaired nutritional status may play pivotal roles in morbidity and mortality. The incidence of wound infections and sepsis has been reduced by correcting the indices of malnutrition in postoperative patients. Malnutrition may also contribute to impaired wound healing, depressed immune response, prolonged postoperative ileus, bowel atrophy, increased respiratory infections and insufficiency, impaired ventilatory responses to hypoxia and hypercarbia, delayed weaning time for patients on ventilators, and prolonged hospitalization. Since many of the above phenomena or characteristics can be linked to radiation exposure alone, their accentuation in the malnourished radiation victim is highly probable.³³

Simple and reliable methods of nutritional assessment are not available, particularly in the irradiated patient, whose lymphocytes will be affected independent of nutritional status. However, parameters that can be used to

assess nutritional status in critically ill patients are serum albumin, transferrin, body weight, allergic skin reactions, thickness of triceps skin fold, and direct assay or clinical evidence of micronutrient deficiencies.³³

In selecting the route of administration of nutrients in the radiation victim, the following considerations are important. The oral route is the safest, most economical, and most natural way to provide nutrients. However, some patients will be unable to consume sufficient quantities of nutrients because anorexia occurs over a wide range of radiation doses. If the alimentary tract has not been injured by radiation, and if inanition supervenes and persists, then nutrients can be infused by nasogastric, gastric, or intestinal feeding tubes. Fluid loss associated with the cholera-like diarrhea of the gastrointestinal subsyndrome may require that nutrients and fluids be administered by both the enteral and parenteral routes. With appropriate placement of an enteral feeding tube, the use of intravenous fluids can be reduced, and transition to enteral therapy alone will be facilitated.³³

The catabolic critically ill radiation casualty will require no less than 2,500-2,800 kcal/day. This requirement can be met by the infusion of a balanced mixture of glucose, amino acids or protein, and lipids. Based on ideal body weight, total protein or amino acid infusion should approach (but not exceed) 2 g/kg/day. Simple carbohydrates (3.5-6.0 g/kg/day) adequately supply most of the 30-40 kcal/kg of nonprotein nutrients needed. Usually, a maximum of 30% of the total caloric requirement can be supplied as lipids. However, short-term peripheral infusion of up to 80% of total calories as lipids is acceptable if central venous access is unavailable.³³

The infusion of micronutrients, including vitamins, minerals, and trace elements, may need to be adjusted with long-term parenteral therapy. The usual daily replacement dosages of essential water- and fat-soluble vitamins, with the exception of vitamin K, are commercially supplied in a single vial. In thermal-burn-injury patients, the requirements for B-complex vitamins and vitamin C are increased. Vitamin K is given as a 10-mg intramuscular injection once a week. If renal impairment supervenes, the normal requirement for potassium (60-100 meq/day), magnesium (8-12 meq/day), and phosphorus (30-60 meq/day) may need to be reduced. Since sodium depletion may occur with diarrhea in the gastro-intestinal subsyndrome, sodium infusion of over 150 meq/day may be needed. If chelation therapy with EDTA is undertaken, supplements of zinc (>4 mg/day), copper (>1.5 mg/day), chromium (>15 µg/day), manganese (>0.8 mg/day), and iron (>2 mg/day) may be needed. The patient who receives multiple blood transfusions will not need iron supplements until after the blood count has stabilized. Trace element supplements, including iodine and selenium, should be considered if prolonged parenteral feeding becomes necessary.³³

VI. INTERNAL RADIATION CONTAMINATION

DISTRIBUTION AND METABOLISM

The routes of intake are inhalation, ingestion, wound contamination, and skin absorption. Within the respiratory tract, particles less than 5 microns in diameter may be deposited in the alveolar area. Larger particles will be cleared to the oropharynx by the mucociliary apparatus. Soluble particles will be either absorbed into the blood stream directly or pass through the lymphatic system. Insoluble particles, until cleared from the respiratory tract, will continue to irradiate surrounding tissues. In the alveoli, fibrosis and scarring are more likely to occur due to the localized inflammatory response. All swallowed radioactive material will be handled like any other element in the digestive tract.^{33, 39}

Absorption. Absorption depends on the chemical makeup of the contaminant and its solubility. For example, radioiodine and cesium are rapidly absorbed; plutonium, radium, and strontium are not. The lower GI tract is considered the target organ for ingested insoluble radionuclides that pass unchanged in the feces. The skin is impermeable to most radionuclides. Wounds and burns create a portal for any particulate contamination to bypass the epithelial barrier. All wounds must therefore be meticulously cleaned and debrided when they occur in a radiological environment. Any fluid in the wound may hide weak beta and alpha emissions from detectors.^{33, 39, 40}

Once a radionuclide is absorbed, it crosses capillary membranes through passive and active diffusion mechanisms and then is distributed throughout the body. The rate of distribution to each organ is related to organ metabolism, the ease of chemical transport, and the affinity of the radionuclide for chemicals within the organ. The liver, kidney, adipose tissue, and bone have higher capacities for binding radionuclides due to their high protein and lipid makeup.^{33, 39, 40}

Medical Management Treatment of internal contamination reduces the absorbed radiation dose and the risk of future biological effects. Administration of diluting and blocking agents enhances elimination rates of radionuclides. Treatment with mobilizing or chelating agents should be initiated as soon as practical when the probable exposure is judged to be significant. Gastric lavage and emetics can be used to empty the stomach promptly and completely after the ingestion of poisonous materials. Purgatives, laxatives, and enemas can reduce the residence time of radioactive materials in the colon.^{32, 33, 39, 40}

PHARMACOLOGIC MECHANISMS FOR RADIONUCLIDE DECORPORATION

A variety of rather simple pharmacologic concepts are exploited in order to rid the body of radioactive contamination (radionuclide decorporation). If radionuclides are in the gastrointestinal tract, speeding up intestinal transit will favor excretion in the stool rather than absorption. A simple laxative thus becomes a radionuclide

decorporation drug. Certain drugs will bind radionuclides in the gastrointestinal tract, making the radionuclides unavailable for absorption. Prussian blue, an unabsorbable dye, works this way for cesium and thallium, including radioactive isotopes of these elements. Flooding the gastrointestinal tract with stable counterparts of the radioactive material will compete with the radioactive material or absorption, and thereby cut down on the absorption of radionuclide. Ingesting calcium salts after strontium (Sr)-90 ingestion is an example of this (calcium is chemically similar to strontium).^{33, 39, 40}

Once the radionuclide enters the blood, one can try to block uptake in the target organ, such as by using non-radioactive potassium iodide to block radioiodide incorporation into thyroid hormone and subsequent storage in the thyroid gland. One can also use propylthiouracil to block the thyroid from taking up radioactive or non-radioactive iodide. One can change the chemical state to one that is less toxic, such as by alkalinizing the urine after uranium ingestion with sodium bicarbonate. This produces uranium bicarbonate which is less nephrotoxic than other forms of uranium. Sometimes diuretics can be used to promote urinary excretion, such as after tritium (H-3) contamination. Chelating agents such as Ca-DTPA and Zn-DTPA may be parenterally administered to chelate a number of radioactive metals and promote their urinary excretion.^{33, 39, 40}

Table VI-1 Medications used to treat and/or remove internal radiation.^{33, 39, 40}

Radio Active Material	Drug	Administered	Comments
Americium	Ca-DTPA, Zn-DTPA	parenteral	
Cesium	Prussian blue	Oral	
Cobalt	Unknown try penicillamine	Oral	nothing too good
Iodine	Potassium Iodide (KI)	Oral	within about first 4 hours
Iridium	Unknown try penicillamine	Oral	nothing too good
Palladium	Unknown try penicillamine	Oral	nothing too good
Phosphorus	Na phosphate or K phosphate.	oral	
Plutonium	Ca-DTPA, Zn-DTPA	parenteral	
Radium	calcium	Oral	Alginates are also useful to reduce gastrointestinal absorption oral to reduce gastrointestinal absorption and increase urinary excretion.
Strontium	Calcium Gluconate and Ammonium	intravenous	oral ammonium chloride for acidification. Alginates are useful to reduce gastrointestinal

	Chloride		absorption.
Tritium	Water	Oral	force water to promote diuresis
Uranium	Ca-DTPA and Zn-DTPA		Na bicarbonate to alkalinize urine.
Yttrium	Ca-DTPA, Zn-DTPA	parenteral	within 4 hours only

Ammonium Chloride

General: This orally administered salt causes acidification of the blood, and is useful for the removal of strontium from the body, especially when combined with intravenous calcium gluconate. Ammonium chloride is given p.o., 1-2 gm q.i.d., for up to 6 consecutive days. Check blood pH or serum CO₂ which will be lowered due to acidification. While best results occur if given quickly after intake, some effect is seen if used up to two weeks afterwards. If used promptly with calcium gluconate, radiostrontium levels can diminish 40-75 %.^{3, 41}

Contradictions: Avoid in patients with severe liver disease.¹⁸

Adverse Reactions: Dizziness, drowsiness, headache, loss of appetite, constipation, nausea or anxiety may occur. If any of these effects continue or become bothersome, inform your doctor. To avoid dizziness when rising from a seated or lying position, get up slowly. Also limit your intake of alcoholic beverages which will aggravate these effects. Also may cause: slow pulse, mental confusion, mood changes, skin rash, breathing trouble.⁴¹

Amifostine (Trade Name Ethyol)

Company: Alza, U.S. Bioscience

FDA Approval Status: Approved December 8, 1995

Treatment for: ovarian cancer

General: Ethyol has been approved to reduce the renal toxicity associated with repeated administration of chemotherapy in subjects with advanced ovarian cancer. Amifostine appears to reduce cisplatin-related nephrotoxicity and radiation-induced esophagitis. Currently, there are only limited data on the effects of Ethyol on the efficacy of chemotherapy in other settings. Ethyol should not be administered to patients receiving chemotherapy for malignancies that are commonly curable, except in the context of a clinical study. Pretreatment with Ethyol significantly reduced the cumulative renal toxicity associated with multiple cycles of chemotherapy.^{42, 43, 44}

Mechanism Of Action: Amifostine is a pro-drug which is activated to the free thiol metabolite at the tissue site. The thiol metabolite is responsible for most of the cytoprotective and radioprotective properties of amifostine. It is readily taken up by cells where it binds to and detoxifies reactive

metabolites of platinum and alkylating agents as well as scavenges free radicals. Other possible effects include inhibition of apoptosis, alteration of gene expression and modification of enzyme activity. Healthy cells are preferentially protected because amifostine and metabolites are present in healthy cells at 100-fold greater concentrations than in tumour cells.¹⁰

Contradictions: Ethyol is contraindicated in patients with known sensitivity to amino-thiol compounds.^{10, 42, 44}

Adverse Reactions: The most common adverse effects of Ethyol were vomiting, low blood pressure, somnolence, and sneezing. Vomiting, hypotension, and somnolence were more common with higher drug doses. In a phase I trial, vomiting and somnolence were experienced significantly more frequently by women than men.^{10, 12} Some of the other side effects were: Blurred vision; confusion; dizziness, faintness, or lightheadedness when getting up from a lying or sitting position suddenly; fainting or loss of consciousness; fast or irregular breathing ; itching; nausea and vomiting ; red, scaly, swollen, or peeling areas of skin; swelling of eyes or eyelids; trouble in breathing; tightness in chest; wheezing; skin rash; sweating ; unusual tiredness or weakness.^{43, 44, 45}

Pregnancy and Breastfeeding: - Amifostine has not been studied in pregnant women. However, in animal studies, large doses caused toxic or harmful effects in the fetus. Because amifostine may cause birth defects or other harmful effects in the fetus, it is usually recommended that women being treated for cancer use birth control. It is not known whether amifostine passes into the breast milk. Breast-feeding is not recommended during treatment.^{43, 44, 45}

Children - Although this medicine has been given to a limited number of children, there is no specific information comparing use of amifostine in children with use in other age groups.^{43, 44, 45}

Calcium (Oral)

A variety of oral calcium supplements are available. One commonly used one is Tums. There are numerous others. Calcium is an alkaline earth, as are strontium, barium, and radium, and a mass effect from calcium can interfere with absorption of the other alkaline earths, and compete with their deposition in bone. In the event of internal contamination with Sr-90 or Ra-226, generous doses of oral calcium preparations should be beneficial.³

Calcium Gluconate

General: Intravenous calcium gluconate is indicated for Sr-90 contamination, and probably Ra-226 contamination as well. Five ampoules, each containing approximately 500 mg calcium, may be administered in 0.5 liter D5W over a 4 hour period. This treatment may be administered daily for 6 consecutive days. It is contraindicated in patients who have a very slow heart rate, those on digoxin preparations, and those on quinidine. Dimercaprol (British antilewisite,

BAL): This agent effectively chelates radioactive and stable nuclides of mercury, lead, arsenic, gold, bismuth, chromium, and nickel.^{3, 44}

Contradictions: Calcium salts are contraindicated in patients with ventricular fibrillation or hypercalcemia. Intravenous administration of calcium is contraindicated when serum calcium levels are above normal.⁴⁴

Pregnancy and Breastfeeding: Pregnancy Category C: Animal reproduction studies have not been conducted with calcium gluconate. It is also not known whether calcium gluconate can cause fetal harm when administered to a pregnant woman or can affect reproduction capacity. Calcium gluconate should be given to a pregnant woman only if clearly needed. It is not known whether this drug is excreted in human milk. Because many drugs are excreted in human milk, caution should be exercised when calcium gluconate is administered to a nursing woman.⁴⁴

Adverse Reactions: About 50% of patients given 6 mg/kg IM developed reactions. These include systolic and diastolic hypertension, tachycardia, nausea, vomiting, chest pain, headache, and sterile abscess at the injection site.⁴⁴

D-Penicillamine

General: This drug chelates nuclides of copper, iron, mercury, lead, gold, and possibly other heavy metals. The chelated metals are excreted in the urine. While this drug is relatively non-toxic, it probably has only limited usefulness for radionuclide decorporation, saving perhaps only 1/3 of the total radiation absorbed dose that would have occurred without treatment. The adult dose is 250 mg p.o. qd between meals and at bedtime. May increase to 4 or 5 g qd in divided doses. Be very cautious if patient has a penicillin allergy.⁴⁴

Adverse Reactions: Side effects of oral d-penicillamine therapy, which is also used for rheumatoid arthritis, Wilson's disease and cystinuria, have been reported, and may be fatal. Many of these are similar to autoimmune disorders and include pruritis, membranous glomerulonephritis, lupus erythematosus (or similar skin eruptions), Goodpasture's syndrome, drug fever, myasthenia gravis, polymyositis, aplastic anemia, thrombocytopenia, and agranulocytosis. Drosos et al have reported the strong association of such side effects with circulating cryoglobulins or autoantibodies in rheumatoid arthritis patients (Drosos 1997). However, oral d-penicillamine in patients with Wilson's disease or cystinuria can also result in similar toxicity. Interruption of d-penicillamine therapy has to be balanced between the risk of interrupting the mother's therapy and the potential toxicity to the fetus. Infants born following in utero exposure have been reported with connective tissue disruption, poor wound healing or

cutis laxa, although most infants exposed to d-penicillamine in utero have been normal.⁴⁸

Short courses of oral d-penicillamine therapy used in children or adults for acute heavy metal overdose have not been associated with such side effects. The only reports of intravenous use of d-penicillamine in humans come from the same group as have reported the ROP results. Among earlier studies on at least 140 term and preterm newborns for the treatment of hyperbilirubinemia, only three infants with side effects were observed: two had mild erythematous rashes that quickly resolved with antihistamines, and one had vomiting which resolved when the drug was stopped. Specific testing of renal and hepatic function were within normal limits on a few selected infants, and growth was not affected. Altogether, small numbers of infants have received intravenous d-penicillamine with few if any side effects. Few data are available on either the acute or long term outcomes of early, short course intravenous d-penicillamine treatment.⁴⁷

Pregnancy and Breastfeeding: The action of D-penicillamine on collagen can cause undesired side-effects. D-penicillamine can be potentially teratogenic, since it crosses the placental barrier. From the literature and the observation of two pregnancies it is shown that among 87 pregnant women who received D-penicillamine 46 cases were treated during the whole period of pregnancy. Two infants from the latter group were found to have severe connective-tissue defects. It is suggest that the dose of D-penicillamine in pregnant patients should be kept as low as possible or not given at all depending upon the radiation dose received.⁴⁸

Potassium Iodide

General: Useful for blocking radioiodine uptake by the thyroid, but needs to be administered almost immediately after exposure. It is virtually useless after 12 hours following a contamination event.¹ The protective effect of potassium iodide lasts approximately 24 hours. For optimal prophylaxis, potassium iodide should therefore be dosed daily, until a risk of significant exposure to radioiodines by either inhalation or ingestion no longer exists. Individuals intolerant of potassium iodide at protective doses, and neonates, pregnant and lactating women (in whom repeat administration of potassium iodide raises particular safety issues, see below) should be given priority with regard to other protective measures (i.e., sheltering, evacuation, and control of the food supply).²¹ Potassium iodide will only protect against exposure to inhaled or ingested radioactive isotopes of iodine. It will not protect against external exposure to radiation and it will not protect against any other radioactive isotope such as plutonium, uranium, cesium or cobalt 60.^{49, 50}

Adverse Reactions: The use of potassium iodide in Poland after the Chernobyl accident provides useful information regarding its safety and

tolerability. The side effects among adults and children were generally mild and not clinically significant. Side effects included gastrointestinal distress, which was reported more frequently in children (up to 2 percent, felt to be due to bad taste of saturated solution of potassium iodide [SSKI]) and rash (approximately 1 percent in children and adults). Two allergic reactions were observed in adults with known iodine sensitivity.⁴⁹

The risks of stable iodine administration include sialadenitis (an inflammation of the salivary gland, of which no cases were reported in Poland among users after the Chernobyl accident), gastrointestinal disturbances, allergic reactions, and minor rashes. Thyroidal side effects of stable iodine include iodine-induced thyrotoxicosis, iodide goiter and hypothyroidism.⁴⁹

Pregnancy and Breastfeeding: Pregnant women should be given potassium iodide for their own protection and for that of the fetus, as iodine (whether stable or radioactive) readily crosses the placenta. However, because of the risk of blocking fetal thyroid function with excess stable iodine, repeat dosing with potassium iodide of pregnant women should be avoided. Lactating females should be administered potassium iodide for their own protection, as for other young adults, and potentially to reduce the radioiodine content of the breast milk, but not as a means to deliver potassium iodide to infants, who should get their potassium iodide directly. As for direct administration of potassium iodide, stable iodine as a component of breast milk may also pose a risk of hypothyroidism in nursing neonates. Therefore, repeat dosing with potassium iodide should be avoided in the lactating mother, except during continuing severe contamination. If repeat dosing of the mother is necessary, the nursing neonate should be monitored as recommended above.⁴⁹

Potassium Phosphate

General: Potassium phosphate is used to block uptake of radioactive phosphate. K-PhosR Neutral contains 250 mg phosphorus per tablet. Phosphate ions are important buffers of the intracellular fluid, and also play a primary role in the renal excretion of hydrogen ion.³

Oral administration of inorganic phosphates increases serum phosphate levels. Phosphates lower urinary calcium levels in idiopathic hypercalciuria. In general, in adults, about two thirds of the ingested phosphate is absorbed from the bowel, most of which is rapidly excreted into the urine.⁵¹

Drug Interactions: The use of antacids containing magnesium, aluminum, or calcium in conjunction with phosphate preparations may bind the phosphate and prevent its absorption. Calcium-containing preparations and/or Vitamin D may antagonize the effects of phosphates in the treatment of hypercalcemia. Potassium-containing medications or potassium-sparing diuretics may cause hyperkalemia.⁵¹

Adverse Reactions: Gastrointestinal upset (diarrhea, nausea, stomach pain, and vomiting) may occur with phosphate therapy. Also, bone and joint pain (possible phosphate-induced osteomalacia) could occur. The following adverse effects may be observed (primarily from sodium or potassium): headaches; dizziness; mental confusion; seizures; weakness or heaviness of legs; unusual tiredness or weakness; muscle cramps; numbness, tingling, pain, or weakness of hands or feet; numbness or tingling around lips; fast or irregular heartbeat; shortness of breath or troubled breathing; swelling of feet or lower legs; unusual weight gain; low urine output; unusual thirst.⁵¹

Contradictions: Contraindicated in hyperphosphatemia, renal insufficiency, and infected phosphate stones.^{3, 51}

Pregnancy and Breastfeeding: Pregnancy Category C. Animal reproduction studies have not been conducted with K-PHOS® NEUTRAL. It is also not known whether this product can cause fetal harm when administered to a pregnant woman or can affect reproductive capacity. This product should be given to a pregnant woman only if clearly needed. It is not known whether this drug is excreted in human milk. Because many drugs are excreted in human milk, caution should be exercised when this product is administered to a nursing woman.⁵¹

Propylthiouracil (PTU)

General: This drug is useful to decrease the thyroid's retention of radioiodine, and may be considered if it is too late for KI to be effective.¹ Propylthiouracil is also used to manage hyperthyroidism which is due to an overactive thyroid gland. It is considered an anti-thyroid agent, like methimazole (Tapazole).¹ Propylthiouracil acts to prevent the conversion of iodine to its useable form. Propylthiouracil also acts to block the combination of converted iodine with other components to form thyroid hormones. This results in a decreased production of thyroid hormones.^{53, 54}

Adverse Effects: PTU is generally well-tolerated with side effects occurring in 1 of every 100 patients. The most common side effects are related to the skin and include rash, itching, hives, abnormal hair loss, and skin pigmentation. Other common side effects are swelling, nausea, vomiting, heartburn, loss of taste, joint or muscle aches, numbness and headache.^{53, 54}

Less common but serious side effects have occurred with PTU therapy. A decrease of white blood cells in the blood (agranulocytosis) may occur. Symptoms and signs of agranulocytosis include infectious lesions of the throat, the gastrointestinal tract and skin with an overall feeling of illness and fever. A decrease in blood platelets (thrombocytopenia) also may

occur. Since platelets are important for the clotting of blood, thrombocytopenia may lead to problems with excessive bleeding. There also have been rare occurrences with PTU of hepatitis and death of liver cells (hepatic necrosis). Failure of the liver due to hepatic necrosis may lead to severe brain swelling, gastrointestinal bleeding, and death.^{53, 54}

Carcinogenicity: Propylthiouracil is reasonably anticipated to be a human carcinogen based on sufficient evidence for carcinogenicity in experimental animals (IARC 1974, 1982, 1987, 2001). When administered in the diet, propylthiouracil induced chromophobe adenomas of the anterior pituitary and carcinomas of the thyroid in mice and solid and cystic type adenomas of the thyroid in female rats. PTU administered in the drinking water induced increased incidences of thyroid carcinomas and adenomas in rats of both sexes, malignant thyroid lesions, with some metastases, in hamsters of both sexes, and thyroid adenomas in male guinea pigs.^{53, 54}

Pregnancy and Breastfeeding: There is evidence that PTU may cause harm to the fetus during pregnancy. If hyperthyroidism becomes more severe during pregnancy, however, PTU may be considered useful under physician supervision. There is also evidence that PTU may cause harm to the fetus during nursing. Use of PTU while nursing should be done under careful physician supervision.^{53, 54}

Prussian Blue (Radiogardase)

General: This oral ion-exchange drug is indicated for decorporation of cesium, thallium, and rubidium, and has been shown to be highly effective for cesium 137 contamination. It is benign, with the exception of occasional constipation. Stool turns blue. may be used.³

Cesium-137 is excreted in the urine and feces. Insoluble Prussian blue, ferric(III) hexacyanoferrate(II), after oral ingestion is not absorbed through the intact gastrointestinal wall. Its clearance from the body depends on the gastrointestinal tract transit time. Insoluble Prussian blue acts by ion-exchange, adsorption, and mechanical trapping within the crystal structure and has a very high affinity for radioactive and non-radioactive cesium and thallium. Insoluble Prussian blue binds cesium and thallium isotopes in the gastrointestinal tract after these isotopes are ingested or excreted in the bile by the liver thereby reducing gastrointestinal reabsorption (enterohepatic circulation).⁵⁵

Insoluble Prussian blue is administered to decrease radiation exposure. It does not treat the complications of radiation exposure. Patients contaminated with high doses of ¹³⁷Cs may develop radiation toxicity including bone marrow suppression with severe neutropenia and

thrombocytopenia. Supportive treatment for radiation toxicity symptoms should be given concomitantly with insoluble Prussian blue treatment. In radiological emergencies, the type of elemental exposure may not be known. Insoluble Prussian blue may not bind to all radioactive elements and some radioactive elements may not undergo enterohepatic circulation which is needed for insoluble Prussian blue binding and elimination. Patients contaminated with unknown or multiple radioactive elements may require treatment with other agents in addition to insoluble Prussian blue.⁵⁵

Contraindications: None

Adverse Reactions: Deaths or serious or severe adverse events attributed to insoluble Prussian blue have not been reported. Constipation was reported in 10/42 (24%) patients in the Goiânia accident treated with insoluble Prussian blue. Severity of constipation was mild in 7 patients and moderate in 3 patients. Constipation was successfully treated with a high fiber diet. Undefined gastric distress was reported in 3 patients treated with 20 gram/day of insoluble Prussian blue. In these patients the dose was reduced to 10 gram/day for continued treatment.⁵⁵

Pregnancy and Breastfeeding: Pregnancy Category C
Comprehensive animal reproductive studies have not been conducted with insoluble Prussian blue. Since insoluble Prussian blue is not absorbed from the gastrointestinal tract, effects on the fetus are not expected. In one patient that became pregnant 3 years and 8 months after being treated with insoluble Prussian blue for internal contamination with ¹³⁷Cs (8 mCi), complications or birth defects were not identified in the literature report. Cesium-137 is known to cross the human placenta. One patient, in Goiânia, was contaminated with 0.005 mCi ¹³⁷Cs during her 4th month of pregnancy. She was not treated with insoluble Prussian blue. At birth the concentration of ¹³⁷Cs was the same in the mother and the infant. Thallium crosses the human placenta. Reported fetal effects in the reviewed literature include fetal death, failure to thrive, alopecia, or in some instances outwardly normal development. The risk of toxicity from untreated radioactive cesium or thallium exposure is expected to be greater than the reproductive toxicity risk of insoluble Prussian blue. Studies to determine if insoluble Prussian blue is excreted in human milk have not been conducted. Since insoluble Prussian blue is not absorbed from the gastrointestinal tract, its excretion in milk is highly unlikely. However, cesium and thallium are transmitted from mother to infant in breast milk. Women internally contaminated with cesium or thallium should not breast feed.⁵⁵

Sodium Alginate

General: A derivative of kelp used in the manufacture of ice cream. Oral alginates efficiently bind strontium in the gastrointestinal tract, and prevent

its absorption.³

The alginates have been shown to bind tightly to strontium, barium, cadmium and radium so that these toxins pass out of the body with little or no absorption. It also binds with lead, but not as completely. Ouch-ouch disease, characterized by painful joints and believed to be caused by oral cadmium exposure, has been successfully treated with alginates in Japan. Reduction in the absorption of strontium has been noted in children given an alginate derivative. Retention of radioactive barium has been reduced in rats fed sodium alginate derivatives. In one human trial, 10 grams of sodium alginate ameliorated acute radiation effects due to exposure to radiation doses of 50 to 3,000 rads.⁵⁶

Sodium alginate may have hypocholesterolemic and glycemic-regulatory activities. It may also have detoxification activity. Sodium alginate has been found to lower cholesterol in animal studies. It is speculated that this may be due to alginate-stimulated increase of fecal bile acid excretion. Sodium alginate has also been demonstrated to lower glucose levels in diabetic animals. The mechanism of this activity is unknown. Sodium alginate binds tightly to such substances as strontium, cadmium, radium and barium. It also binds to lead, but not as well. Sodium alginate's binding to these substances reduces their absorption.⁵⁶

Adverse Reactions: Gastrointestinal symptoms such as flatulence may occur with sodium alginate supplements. Sodium alginate may decrease the absorption of the carotenoids beta-carotene, lycopene and lutein if used concomitantly. It may also decrease the absorption of such minerals as calcium, zinc, manganese, chromium and magnesium if used concomitantly.⁵⁶

Contradictions: Sodium alginate is contraindicated in those who are hypersensitive to any component of a sodium alginate-containing product.⁵⁶

Sodium Bicarbonate

General: Used to alkalinize the urine after uranium intake, which protects the kidneys from uranium deposition. Oral or intravenous, take as needed to maintain alkaline urine.¹ Intravenous sodium bicarbonate therapy increases plasma bicarbonate, buffers excess hydrogen ion concentration, raises blood pH and reverses the clinical manifestations of acidosis.⁵⁷

Adverse Effects: May include stomach cramps that continue and or nausea, headache, and appetite loss (with long-term use). Rarely patients will exhibit Muscle pain or twitching, nervousness, breathing difficulty, mild swelling of feet or lower legs (with large doses).⁵⁷

Contradictions: Avoid for patients with high blood pressure have high blood pressure.⁵⁷

Pregnancy and Breastfeeding: May cause weight gain and swelling of feet and ankles. No problems expected during nursing.⁵⁷

Sodium Phosphate: See potassium phosphate. Also used for radioactive phosphate de-corporation.³

Trisodium Calcium Diethylenetriaminepentaacetate (Ca-DTPA)

Ca-DTPA is distributed by Oak Ridge Associated Universities (ORAU) under contract with the U.S. Department of Energy (DOE), Contract No. DE-AC05-76OR00033. ORAU manages the FDA Investigational New Drug (IND) authorizations for Ca-DTPA and the analogous Zn-DTPA for DOE.⁵⁸

IND 4041, Trisodium calcium diethylenetriaminepentaacetate (Ca-DTPA), is a calcium salt of DTPA. It has been used in the U.S. as a chelating agent for plutonium and other transuranic elements such as americium, californium, and curium. DTPA is also used in lesser concentrations as a chelating vehicle in FDA-approved nuclear medicine studies.⁵⁸

General: This is a powerful and stable chelating agent, which has been used primarily to remove plutonium and americium. It chelates transuranic ($Z > 92$) metals (plutonium, americium, curium, californium, and neptunium), rare earths such as cerium, yttrium, lanthanum, promethium, and scandium), and some transition metals (such as zirconium and niobium). In normal, healthy, non-pregnant adults with normal bone marrow and renal function, the dose to use is 1 gm in 250 ml normal saline or 5% dextrose in water, iv over 1 hour. No more than 1 dose per day should be used, and the dose should *not* be fractionated. May use for several days to a week in most cases without toxic effects.³

The same dose and dose schedule is used for Zn-DTPA as for Ca-DTPA. While the DTPA compounds are best used as quickly as possible after internal contamination, they are effective if given later, but therapy may go on for months or even years. The DTPA compounds are only effective if the metals one wishes to chelate are in ionic form. They are useless for highly insoluble compounds.³

Contraindications: Ca-DTPA is contraindicated for minors, pregnant women, patients with the nephrotic syndrome, and in patients with bone marrow depression. (Such patients may be treated with Zn-DTPA.) Ca-DTPA should not to be used as a chelator for uranium or neptunium. Internal contamination with uranium is currently treated by alkalizing the urine with bicarbonate in order to promote excretion. DTPA has also been

postulated to form an unstable complex with neptunium, which may increase bone deposition of this actinide.^{58, 59}

Adverse Reactions: No serious toxicity in human subjects has been reported as a result of over 4500 Ca-DTPA administrations in recommended doses. When given repeatedly, with short intervals for recovery, Ca-DTPA treatment may cause nausea, vomiting, diarrhea, chills, fever, pruritus, and muscle cramps in the first 24 hours. Anosmia (loss of the sense of smell) was observed in one individual after 123 g of Ca-DTPA over twenty-seven months of therapy and possibly could have been related to zinc depletion. After 100 days of no further DTPA administration, the patient's sense of smell improved. Toxicity is mainly due to chelation of needed metals, such as Zn and Mn.^{3, 58, 59}

Pregnancy and Breastfeeding: Pregnancy Category D. Teratogenicity and fetal death have occurred in mice following five daily injections of 720-2880 Fmol Ca-DTPA/kg given throughout the gestation. However, daily doses of 360 Fmol Ca-DTPA/kg in mice, about 10 times the daily human dose, produced no harmful effects. Studies of 2 pregnant beagles given daily injections of Ca-DTPA at 30 Fmol/kg, a daily dose comparable to 1 g in a 70 kg man, starting at 15 days of gestation until the end of pregnancy, have shown severe effects (especially brain damage in the fetuses).^{3, 58}

Trisodium Zinc Diethylenetriaminepentaacetate (Zn-DTPA)

General: Trisodium zinc diethylenetriaminepentaacetate (Zn-DTPA), is a zinc salt of DTPA. It has been used in the U.S. as a chelating agent for plutonium and other transuranic elements such as americium, californium, and curium. DTPA is also commonly used in lesser concentrations as a chelating vehicle in FDA-approved nuclear medicine studies.⁵⁹

Zn-DTPA is distributed by Oak Ridge Associated Universities (ORAU) under contract with the U.S. Department of Energy (DOE), Contract No. DE-AC05-76OR00033. ORAU manages the FDA Investigational New Drug (IND) authorizations for Zn-DTPA and the analogous Ca-DTPA for DOE. The current supply of Ca-DTPA has been purchased from Heyl GmbH, Berlin, Germany and has been tested extensively by them for chemical stability and chemical purity and by an independent testing company for pyrogenicity.⁵⁹

Before, during and after chelation therapy, pertinent measurements for radioactivity should be made to determine the efficacy of treatment. By the fifth day, evaluate bioassay data for body-burden estimation and decide whether further chelation is necessary. If so, a Zn-DTPA treatment regimen should be implemented.⁵⁹

Zn-DTPA is initially 10 times less effective than Ca-DTPA for initial chelation of transuranics; therefore, Ca-DTPA should be used whenever

larger body burdens of transuranics are involved. Ca-DTPA is the drug of choice for initial patient management unless contraindicated. After approximately 24 hours, however, Zn-DTPA is for all practical purposes as effective as Ca-DTPA, since the efficiency of both agents is about the same. The comparable efficacy, coupled with its lesser toxicity, makes Zn-DTPA the preferred agent for protracted therapy.⁵⁹

Adverse Reactions: Zn-DTPA results in minimal depletion of magnesium and manganese.^{60,61}

Contradictions: Zn-DTPA should not to be used as a chelator for uranium or neptunium. Internal contamination with uranium is currently treated by alkalinizing the urine with bicarbonate in order to promote excretion. DTPA has also been postulated to form an unstable complex with neptunium, which may increase bone deposition of this actinide.^{60,61}

Fractionation of the recommended 1 g dose (several smaller doses per day) is not recommended although Zn-DTPA does not appear to have the increased toxicity of Ca-DTPA (associated with fractionated treatment).³⁰

Pregnancy: Pregnancy Category C. The chelates do not significantly cross-placental barriers. There have been several studies indicating the lack of teratogenic effects by Zn-DTPA at doses up to several times the human intravenous dose of 0.0287 mmol/kg. In these experiments, Zn-DTPA did not show toxicity during pregnancy as did Ca-DTPA. In pregnant mice given a daily dose of 11.5 mmol/kg (400 times the human dose), the only fetal effect observed was a slight reduction in the average birth weight.⁷ Zn-DTPA is therefore preferred over Ca-DTPA in pregnancy and should be used, if available, to treat a pregnant female with internal transuranic contamination. However, there are no adequate and well-controlled studies of Zn-DTPA in pregnant women. The potential benefits of transuranic decorporation must therefore be weighed against the risk to the fetus.^{60,61}

FURTHER INPATIENT CARE

During periods of infection, antibiotics should be tailored toward the source of infection. If absolute neutrophil count (ANC) is less than 500 cells/mm³, most experts recommend prophylactic antibiotics including a fluoroquinolone, an antiviral agent (acyclovir in those with a history of herpes simplex virus), and an antifungal agent. Once fever and infection occur, broader antibiotics with additional antipseudomonal coverage should be initiated.²

The use of bone marrow transplants remains controversial. Of the 13 Chernobyl victims who received bone marrow transplants, only 2 survived, one of whom had autologous marrow repopulation; thus only one survivor was thought to be saved by a bone marrow transplant. The dose window appropriate for bone marrow transplantation is thought to be between 8 and 10 Gy, as those who receive less

than 8 Gy may survive with conservative treatment, antibiotics, and transfusions, whereas those who receive greater than 10 Gy uniformly die.²

Administration of hematopoietic growth factors to stimulate bone marrow post irradiation also remains investigational. Past studies have shown a benefit in animal models increasing neutrophil counts in primates irradiated with Cobalt-60. In a 2004 paper, Waselenko et al proposed recommendations for giving colony-stimulating factors (CSF) to victims of radiation exposure. His team recommended giving granulocyte-macrophage colony-stimulating factor (GM-CSF) to those who receive more than 3 Gy of radiation and in those with multiple injuries who are exposed to more than 2 Gy. Recommended doses include initiating therapy with filgrastim at 5 $\mu\text{m}/\text{kg}/\text{day}$ or sargramostim at 250 $\mu\text{m}/\text{m}^2/\text{day}$ subcutaneously immediately after exposure and continuing until absolute neutrophil count increases to greater than 1,000 cells/ mm^3 . Alternative treatment with subcutaneous pegfilgrastim weekly to those greater than 45 kg has also been suggested.²

VII. LATE EFFECTS OF IONIZING RADIATION

RADIATION EXPOSURE AND HEALTH EFFECTS

The mechanisms that lead to adverse health effects after ionizing radiation exposure are not fully understood. Ionizing radiation has sufficient energy to change the structure of molecules, including DNA, within the cells of the body. Some of these molecular changes are so complex that it may be difficult for the body's repair mechanisms to mend them correctly. However, the evidence is that only a small fraction of such changes would be expected to result in cancer or other health effects.⁶²

The most thoroughly studied individuals for the evaluation of health effects of ionizing radiation are the survivors of the Hiroshima and Nagasaki atomic bombings, a large population that includes all ages and both sexes. The Radiation Effects Research Foundation (RERF) in Japan has conducted follow-up studies on these survivors for more than 50 years. An important finding from these studies is that the occurrence of solid cancers increases in proportion to radiation dose. More than 60% of exposed survivors received a dose of radiation of less than 100 mSv (the definition of low dose used by the BEIR VII report).⁶²

BEIR VII develops the most up-to-date and comprehensive risk estimates for cancer and other health effects from exposure to low-level ionizing radiation. It is among the first reports of its kind to include detailed estimates for cancer incidence in addition to cancer mortality. In general, BEIR VII supports previously reported risk estimates for cancer and leukemia, but the availability of new and more extensive data have strengthened confidence in these estimates. A comprehensive review of available biological and biophysical data supports a "linear-no-threshold" (LNT) risk model—that the risk of cancer proceeds in a linear fashion at lower doses without a threshold and that the smallest dose has the potential to cause a small increase in risk to humans.⁶²

In general, the amount and duration of radiation exposure affects the severity or type of health effect. There are two broad categories of health effects: stochastic and non-stochastic.⁶²

STOCHASTIC HEALTH EFFECTS

Stochastic health effects are associated with long-term, low-level (chronic) exposure to radiation. ("Stochastic" refers to the likelihood that something will happen.) Increased levels of exposure make these health effects more likely to occur, but do not influence the type or severity of the effect.⁶²

Cancer is considered by most people the primary health effect from radiation exposure. Simply put, cancer is the uncontrolled growth of cells. Ordinarily, natural processes control the rate at which cells grow and replace themselves. They also control the body's processes for repairing or replacing damaged tissue.

Damage occurring at the cellular or molecular level, can disrupt the control processes, permitting the uncontrolled growth of cells--cancer. This is why ionizing radiation's ability to break chemical bonds in atoms and molecules makes it such a potent carcinogen.⁶²

Other stochastic effects also occur. Radiation can cause changes in DNA, the "blueprints" that ensure cell repair and replacement produces a perfect copy of the original cell. Changes in DNA are called mutations.⁶²

Sometimes the body fails to repair these mutations or even creates mutations during repair. The mutations can be teratogenic or genetic. Teratogenic mutations are caused by exposure of the fetus in the uterus and affect only the individual who was exposed. Genetic mutations are passed on to offspring.

NON-STOCHASTIC HEALTH EFFECTS

Non-stochastic effects appear in cases of exposure to high levels of radiation, and become more severe as the exposure increases. Short-term, high-level exposure is referred to as 'acute' exposure.⁶²

Many non-cancerous health effects of radiation are non-stochastic. Unlike cancer, health effects from 'acute' exposure to radiation usually appear quickly. Acute health effects include burns and radiation sickness. Radiation sickness is also called 'radiation poisoning.' It can cause premature aging or even death. If the dose is fatal, death usually occurs within two months. The symptoms of radiation sickness include: nausea, weakness, hair loss, skin burns or diminished organ function.⁶²

Medical patients receiving radiation treatments often experience acute effects, because they are receiving relatively high "bursts" of radiation during treatment.⁶²

COHORT STUDIES OF JAPANESE ATOMIC BOMB SURVIVORS

Early effects include various acute radiation symptoms. Information on these symptoms was obtained by interviewing more than 100,000 atomic-bomb survivors primarily from 1956 to 1961. Survivor recollections of the traumatic day were highly subjective, possibly resulting in biased data regarding early effects.⁶⁴

In general, acute radiation symptoms do not appear at low-dose radiation exposures, giving rise to a concept known as a threshold dose. That is, below a certain radiation dose, no acute symptoms occur. This is in contrast to a theory known as the linear dose-response relationship, which is illustrated by malignant diseases, one of the most well established late effects of radiation exposure. This concept implies that the higher the radiation dose, the greater the risk of developing a malignancy.⁶⁴

Birth Defects There is no statistically demonstrable increase in major birth defects considered in total or in any specific type among the children of atomic-bomb survivors. This assertion rests on a continuous prospective surveillance of the children conceived and born in Hiroshima and Nagasaki after the bombings. The survey began in the late spring of 1948 and continued over the following six years. During that time, 76,626 newborn infants in Hiroshima and Nagasaki were examined by physicians employed by the Atomic Bomb Casualty Commission (ABCC), the predecessor of the present Radiation Effects Research Foundation. When the surveillance began, certain dietary staples were rationed in Japan, as they had been throughout much of the war, but in the interests of health, the ration regulations made special provision for pregnant women. The system of surveillance was tied, therefore, to the process wherein pregnant women registered for supplementary rations. Through this means, it was possible to identify more than 90% of the pregnancies in these cities that persisted for at least 20 weeks of gestation (the earliest stage in pregnancy when the additional rations were made available) and to examine the outcomes at birth and thereafter.⁶⁵

Chromosome Mutations Chromosome examinations have been done for 8,322 persons born to parents one or both of whom were proximally exposed to the atomic bombings and for 7,976 persons born to parents (1) one or both of whom were exposed distally or (2) who were not exposed.⁶⁶

The results showed a total of 18 persons bearing chromosome abnormalities in the radiation-exposed group and 25 in the control group. Subsequent tests of the parents showed that the majority of the abnormalities were inherited from either parent. Only one abnormality in the exposed group and one in the control group were newly arisen mutations. That is, four abnormalities in the exposed group and eight in the control group were inherited from the father, whereas no abnormalities in the exposed group and two in the control group were inherited from the mother. The origin of six abnormalities and five abnormalities for the exposed and control groups, respectively, could not be determined, but are considered to be inherited because siblings showed the same abnormalities.⁶⁵

RERF Life Span Study (LSS) Cohort studies of Japanese atomic bomb survivors are being conducted by the Radiation Effects Research Foundation (RERF) to characterize the long-term health effects of radiation. The RERF LSS includes more than 86,000 Japanese atomic bomb victims with individual dose estimates who were living in the cities in late 1950. There is virtually complete mortality follow-up since 1950 and cancer morbidity data are available from 1958. The results of recent analyses of these data are presented in (Table IX. 3).⁶⁴

LSS Solid Cancer Incidence Data Table IX .1 summarizes the LSS solid cancer incidence data for the period from 1958 through 1995. Although only seven dose categories are shown in this table, the analyses are carried out using a much more detailed person year table with more than 24,000 records. The expected number of cases are based on a semi-parametric model in which rates for the unexposed are described using stratification on gender, city, age at exposure and birth cohort (more than 450 strata) with the radiation-associated excess relative risk modeled as a gender, age and age at exposure dependent linear function of dose.⁶⁴

Table VIII-1 Atomic bomb survivor solid cancer incidence Hiroshima and Nagasaki 1958 - 1995⁶⁵

Dose (Sievert)	People	Person Years	Observed Cases	Expected Cases	Radiation-Associated Cases	Attributable fraction
< 0.005	34,582	1,003,500	4,845	4,842	3	0%
0.1	29,352	849,511	4,143	4,095	48	1%
0.2	5,316	151,970	871	789	82	9%
0.5	5,897	166,684	1,034	862	172	17%
1.0	3,057	86,252	614	427	187	30%
2.0	1,503	42,423	388	200	188	48%
>2.0	436	11,805	114	48	66	58%
Total	80,143	2,312,145	12,009	11,263	746	6%

The rightmost columns in this table clearly indicate a dose response although only about 6% of the 12,000 cancer cases are associated with the radiation exposure. Since radiation-associated cancers are (currently) indistinguishable from those in which radiation had no effect, careful statistical analyses are crucial to our understanding of the nature of radiation effects on cancer. Extensions and alternatives to the standard survival analysis methods and models are crucial to the understanding radiation risks on disease risks in the atomic bomb survivors.⁶⁴

HEALTH EFFECTS OF THE CHERNOBYL ACCIDENT

Scientists and experts from the Republic of Belarus, Russian Federation, Ukraine, and other countries, as well as representatives of international organisations [the World Health Organisation (WHO), the United Nations Office for the Co-ordination of Humanitarian Affairs (OCHA), the International Atomic Energy Agency (IAEA), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the United Nations Chernobyl Programme in Ukraine], and the International Commission on Radiological Protection (ICRP)] participated in the work of the conference. The Conference paid tribute to the medical personnel whose expertise and commitment minimised acute radiation effects in persons involved in the early stages of the accident and to the international medical community for invaluable response and humanitarian assistance.⁶³

Stochastic Health Effects of radiation from the Chernobyl accident were documented as:⁶³

- There is no doubt that the incidence of thyroid cancer has substantially increased in children who were 0-18 years old at the time of the accident and that this is related to radiation from the accident. An increased number of cases of thyroid cancer among liquidators who worked in 1986 is expected to occur.
- There is a tendency of an increase of leukaemia among liquidators who worked on the site in 1986 and 1987 and who received significant doses. So far a statistically significant excess has been observed only in Russian clean-up workers. In those of the Republic of Belarus and Ukraine no significant excess has been observed to date.
- There is no significant increase of leukaemia in adults or children living on contaminated territories of the three affected countries.
- While there has been increased incidence of solid tumours, there is little significant and/or consistent evidence of a radiation-related increase in clean-up workers, evacuees, or residents of contaminated areas in the three affected countries.
- Stable changes in chromosomes of somatic cells have been identified after the accident. Research is required to determine whether similar changes may lead to increased incidence of disease in offspring.

Deterministic Health Effects of radiation from the Chernobyl accident were documented as:⁶³

- Bone marrow syndrome was diagnosed in 134 persons who received 1-12 Gy of relatively uniform whole-body exposure during the early stages of the accident. Supportive medical care provided to these individuals resulted in substantial survival. However, 28 died during the first three months after the accident. In later years 14 additional deaths, attributable to a variety of medical conditions, have occurred.
- Various somatic disorders, including delayed neuropsychiatric complications and radiation skin damage, have been observed in survivors of bone marrow syndrome. Cataracts are seen in survivors at a level related to dose.
- It is anticipated that information on the development of cataracts in clean-up workers and others who may have received significant exposures will soon be available as well.
- There are indications that the incidence of cardiovascular, cerebrovascular and thyroid diseases in clean-up workers and possibly other non-cancer conditions may be increased; radiation exposure or other factors may play a role in this increase.

Other Health Effects At 15 years after the accident other types of health effects seem to have emerged. These are primarily neuropsychiatric and cardiovascular diseases, but also include:⁶³

- Deteriorating health of liquidators;
- Increasing invalidity among liquidators;
- Decreased birth rate;
- Diminished health of new-borns;
- Increased pregnancy complications;
- Impaired health of children.

A number of factors inherent to the Chernobyl accident, including worsening socio-economic conditions, continuing residence in contaminated territories, diminished food supply, vitamin deficiency, relocation, and psychological stress, may contribute to these effects.⁶³

VIII. PSYCHOLOGICAL FACTORS OF RADIATION EXPOSURE

PSYCHOLOGICAL IMPACT OF RADIATION EXPOSURE

An attack using radiation will create uncertainty, fear, and terror. Following the detonation of a RDD the management of acute psychological and behavioral responses will be as important as the treatment of RDD-related injuries and illnesses. Radiation is a dreaded threat, usually seen as catastrophic and fatal. Radiation is invisible, odorless and unknown. These ingredients stimulate worst-case fantasies. People must rely on health care providers and scientists to determine whether or not a person has been contaminated. Radiation exposure may not be manifest immediately. The health effects of radiation can be delayed in time, not only affecting those exposed but also future generations. Those who have been exposed or anticipate possible exposure feel a sense of vulnerability, anxiety, and a lack of control. The common lack of consensus among experts can increase public fear and anger.²⁹

Psychosocial issues must be addressed in the potentially exposed population. Since a primary objective of terrorism is to elicit psychological shock, many persons requiring medical treatment will develop psychosocial symptoms even in the setting of no radiation exposure or very-low-dose exposure. Accordingly, terrorists will exploit an inherent, widespread fear of radiation by the general public to achieve a psychological effect.³³

For the vast majority of people, distress and psychological and behavioral symptoms related to the traumatic event exposure will diminish over time. For others, however, symptoms will persist, affect function at home and work, and may result in psychiatric illness. In addition to acute stress disorder and posttraumatic stress disorder, major depression, increased substance use, family conflict, and generalized anxiety disorder are also encountered. People with no psychiatric history are vulnerable to psychiatric illness after terrorism, but those at greatest risk include people directly exposed (ie, near the blast or involved in rescue and recovery of victims and remains), those with previous mental illness, and those who experience loss of property or disruption of their social supports as a consequence of the incident.³⁷

Approximately 75% of individuals exposed to nuclear weapon detonations exhibit some form of psychological symptoms, ranging from inability to sleep to difficulty concentrating and social withdrawal. Among those at highest risk for significant psychological effects are children, pregnant women, mothers of young children, participants in radiation cleanup, and people with a medical history of a psychiatric disorder. In addition, exposed individuals and their families and friends have a high rate of post-traumatic stress disorder.³³

Post-Traumatic Stress. Symptoms associated with post-traumatic stress disorder include anxiety disorders, depression, and a recurrent sense of re-

experiencing the traumatic event. Individuals may exhibit outbursts of anger, an exaggerated startle response, and increased irritability. Post-traumatic stress disorder can be diagnosed when these symptoms persist for more than 1 month.³³

The number of individuals without exposure (that is, <0.25 Gy) who require psychosocial support is far greater than the number of patients who would be physically injured. Expeditious triage of the former victims is essential and provision of appropriate treatment in the ambulatory setting is required so that those with survivable injuries can receive supportive care.³³

Mental Health Professionals. Mental health professionals should be an integral part of the teams performing initial screening and triage of potentially exposed victims. Providing food and shelter in a safe environment, facilitating communication with family and loved ones, limiting exposure to reminders of the event, and directing victims to available services and support are all critical elements of psychological first aid, but the first priority must be the provision of good medical care. Assessing and recording the patient's specific concerns and making arrangements for followup (rather than advising the patient to "return if there is a problem") will mitigate the patient's psychological distress. Providing accurate information about the risks of exposure and available medical countermeasures will also lessen fear, concern, and distress. Some patients, such as pregnant women, the parents of small children, and children themselves, have special needs and may require additional attention. Patients may also be concerned about the long-term risk of developing cancer, and this concern may persist for years after the event in question.³³

Healthcare Providers and Mental Health Care after a Radiation Event

Following a radiologic event, people will likely turn to healthcare providers for information and guidance. For example, following the 2001 anthrax attacks, 77% of a representative sample of Americans reported that they would trust their own doctor most as a reliable source of information.²⁹

Healthcare providers play a key role in determining how patients and the general public respond to a radiological terrorist event. A well-organized, effective medical response will instill hope and confidence, reduce fear and anxiety, and support the continuity of basic community functions. Healthcare providers are also subject to fear and terror. Absenteeism, flight, refusal to see patients, and other fear-organized behaviors have been reported following infectious disease outbreaks (such as the outbreak of pneumonic plague in Surat, India) and other instances of new or unfamiliar, life-threatening agents.²⁹

Some healthcare providers are prompted by concerns for their personal safety. At times health care providers, like others, have fled their health care

responsibilities. Many of those who abandon their responsibilities do so because they feel they need to protect their families, often by evacuation. Ensuring that health care providers understand radiation and countermeasures for protection can minimize role abandonment. Perhaps most importantly, health care providers are more likely to provide patient care if they believe that their families will be taken care of in their absence – e.g. are given potassium iodide, etc. The availability of ongoing telephone contact with families and dedication of personnel to assist health care provider's families will be reassuring to health care providers and help them focus on their mission.²⁹

The Term “Worried Well”. The term “worried well” and similar disparaging terms should never be used. When labels suggesting “it’s all in your head” are used, patients feel stigmatized and that their health concerns have not been taken seriously. The use of such labels contributes to mistrust of the medical community and a loss of its credibility. A non-stigmatizing triage labeling system such as “high risk”, “moderate risk”, “minimal risk” conveys continued concern and monitoring which is reassuring to patients.²⁹

Emergency Services Extended Care Center” (ESECC). The establishment of an ESECC) offers an important means of monitoring patients, who remain fearful and are not reassured by negative findings. In the event that a patient is misdiagnosed, the patient can be accompanied back to the Emergency Department. Patients with minor physical problems who cannot return home can be referred here. Ideally, there would be simple tasks that the patients can perform while in the ESECC will help them transition out of the patient role and restore their sense of control.²⁹

IX. MANAGEMENT OF HUMAN REMAINS EXPOSED TO IONIZING RADIATION

INTRODUCTION

There are several scenarios involving accidents, terrorist attacks, or medical treatments that could result in radioactively contaminated fatalities. Examples include a transportation accident involving radioactive material, a reactor accident, activation of a radiological dispersal device, detonation of a nuclear weapon, or release of a body injected with a radiopharmaceutical or brachytherapy seeds from a hospital.⁶⁶

Although there are laws regulating radioactive material in live patients or in industrial materials there are no federal regulations regulating radioactive material in human remains. There is some published guidance on special cases of radioactively contaminated decedents, such as from medical sources, transportation accidents, or the military. There are state regulations or common carrier policies for shipment of decedents; and federal regulations for shipment of radioactive material.⁶⁶

There have been very few exercises in recent years involving radioactively contaminated fatalities, and those generally end with remains recovery at the scene without involving medical examiners, coroners, or morticians.

At the same time that work on these guidelines was in progress, the National Association of Medical Examiners (NAME) was preparing its own guidelines for dealing with contaminated decedents and the National Council on Radiation Protection and Measurements (NCRP) was revising its report on handling contaminated persons to include a chapter on fatalities. The authors of these three documents worked together to ensure all three final guidelines would be consistent.⁶⁶

A deceased person who has been externally exposed to a lethal amount of radiation does not become radioactive as a result of the exposure. No special precautions are needed. For example, cancer patients who die after external radiotherapy do not need special handling precautions.¹⁷

Special precautions are necessary when patients are contaminated and have radioactive material on them or in them. It is imperative to determine the presence of significant radioactivity and the dose rate with a Geiger or ionization type meter before recovering or removing potentially radioactively contaminated bodies. It may be necessary to remove the body from a radiation area to determine whether the body is truly contaminated. When dealing with any contaminated body, it is essential to have protective clothing (e.g., gloves, mask and gown or jumpsuit), a personal dosimeter, and if possible, somebody with radiation protection expertise. Before removing a contaminated body from the scene, there should be an appropriate radiation tag placed.¹⁷

Radioactive contamination may occur in three ways as a result of a terrorist

incident: ^E

External contamination with radioactivity on the clothing or skin. Deaths are not likely as a result of a non-explosive RDD, but an RDD or IND with associated explosion, or fallout from a weapon or reactor would likely result in significant external contamination. The external contamination would not only be on the body but also on the ground. The dose rate from this contamination may preclude entry into the area and recovery of bodies may have to wait until some of the radioactivity has decayed or shielding can be arranged. ¹⁷

Based on the Chernobyl experience, once a person has been removed from the radiation area, it is very unlikely that particulate radioactivity or radioactive fallout will result in a significant hazard to attendants who are wearing protective garb. Doses received by Chernobyl attendants were in the range of 10 mSv (0.01Gy). The most effective quick method of reducing external contamination and decreasing attendant exposure is removal of the external clothing. This should be done as soon as practical. The clothing should be bagged and tagged. ¹⁷

Internal contamination is loose radioactive material that has gotten into the body through inhalation, wounds, skin, or rarely ingestion. Experience with radiotherapy patients who have received large amounts of unsealed radionuclides has shown that there is little hazard to providers as long as protective clothing is worn. Pathologists performing autopsies on internally contaminated patients have received less than 5 mSv (.005Gy). ¹⁷

Radioactive shrapnel is a major potential hazard for attendants. Some radioactive shrapnel may emanate from very radioactive metallic sources or reactor cores. These sources will likely be emitting penetrating gamma radiation. Highly radioactive cadavers will most likely be near the center of an explosion. In such areas, the radiation dose rate must be measured as outlined above. The radiation dose to attendants is a direct function of distance from the body and in some circumstances could exceed occupational dose limits. Evaluation by radiation safety personnel is essential before handling such highly contaminated bodies. Metallic radioactive items should never be handled directly, only with instruments. If such sources are removed from the body, they should be placed in a shielded container in a secure location. ¹⁷

MASS CASUALTIES

In the event of a mass casualty, the Department of Homeland Security may activate the Federal Response Plan and the National Disaster Medical System (NDMS). NDMS assets include Disaster Mortuary Operational Response Teams (DMORTs). A DMORT is a Federal response team designed to provide mortuary assistance in the case of a mass fatality incident or cemetery-related incident. A DMORT works under the local jurisdictional authorities such as Coroner/Medical

Examiners, Law Enforcement and Emergency Managers. There are 10 Regional DMORT Teams, one in each of the 10 FEMA Regions. In addition there is one Weapons of Mass Destruction (WMD) DMORT, which can decontaminate between 5 to 50 deceased persons per hour in the field.¹⁷

Deaths Caused by Detonation of a Nuclear Weapon The detonation of a nuclear weapon would produce both initial and delayed deaths. Initial deaths would include persons at or near ground zero killed by blast, heat, or flying objects. Delayed deaths would include persons who died because of injuries sustained in the initial blast, persons who died from acute radiation syndrome, and persons who died from a combination of injuries and acute radiation syndrome. (One deterministic effect is suppression of the immune system, making burn victims more difficult to treat.)⁶⁶

Persons who die immediately because of the blast could have external contamination on their skin and clothes. They will not have internal contamination if they died before they had time to inhale or ingest radioactive material. Because everything inside the fireball is vaporized, radioactive shrapnel is not likely.⁶⁶

Persons who die hours or days later might have inhaled or ingested radioactive material. Their internal contamination cannot be eliminated, but the dose rates from this source of contamination will be too low to pose a health risk for other persons in the vicinity of the body.⁶⁶

Deaths Caused by a Radiological Dispersal Device Immediate deaths from a dirty bomb would be caused by the blast itself, not the radioactivity. The decedents might have external contamination or shrapnel. Delayed fatalities could be caused by injuries suffered in the blast, by acute radiation syndrome, or a combination of the two. These decedents could have internal contamination.⁶⁶

Radioactive Source in a Public Place A high-level radioactive source in a public place (e.g. movie theater or city bus) could expose a large number of persons to enough radiation to cause deterministic effects. The symptoms of acute radiation syndrome (e.g. skin burns, influenza-like symptoms) could take days or weeks to develop. Many persons could develop symptoms of acute radiation syndrome before the first deaths.⁶⁶

MEDICAL EXAMINER/CORONER RADIATION PROTECTION PRECAUTIONS AT THE SCENE

The incident commander should designate a radiation safety officer to oversee the radiological precautions, select the instruments to be used, and establish administrative limits on radiation doses for all workers. The annual limit on dose to a radiation worker is 5 rem.⁶⁶

If the cause of death was detonation of a nuclear weapon, consider delaying remains recovery operations for one or two days to allow the fission products to decay. If the cause of death was a dirty bomb, there is no benefit to delaying operations.⁶⁶

In addition to the normal protocols for human remains removal, the radiation safety officer should cordon off the area and designate a person to control entry and egress. In a nuclear power plant this person is called the “control point watch” and his station the “control point.” The control point watch will record the name, time in, dosimeter serial number, dosimeter reading in, time out, and dosimeter reading out for each person entering the scene.⁶⁶

All people working in the controlled area should carry two dosimeters. They should have a thermoluminescent dosimeter (TLD) inside their protective clothing and a self-reading dosimeter (Figure 5 or 7) outside the protective clothing where they can read it. The TLD reading will eventually constitute the legal record of exposure. The self-reading dosimeter is for safety, but in an emergency it can be used as the legal record of exposure.⁶⁶

Before the human remains removal team enters the area, two people should enter and conduct an initial survey using an omnidirectional probe. To prevent contamination of the instrument, the probe and the meter should be wrapped in clear plastic. Observe the instrument during the entry to ensure it does not saturate.⁶⁶

The two people should stay in sight of one another for safety. One person will move around the scene pausing to measure and announce dose rates. The other person will remain in a low dose rate area and record the dose rates on a map or sketch of the area. The map showing locations of the bodies and dose rates in the area will be used by the remains recovery team to plan their operations.⁶⁶

The body inside the human remains pouch (HRP) is emitting radiation, so the HRP or container cannot be frisked at the control point. Swipe the container with a piece of tissue, place the swipe paper on a clear surface away from the body, and check it with the pancake probe to ensure the exterior of the HRP is free of contamination. If there is no possibility of alpha- or beta-emitting isotopes, wrap the pancake probe in plastic to prevent its contamination.⁶⁶

There should be a table outside the cordoned off area at the control point, divided into a clear and a contaminated section. When the initial survey team exits the area, each piece of equipment – survey instrument, radio, dosimeter, etc – should be surveyed the by control point watch or another team member wearing gloves and using a pancake probe. The surveys should be done in accordance with FEMA guidelines (Table 2) (16) or vendor’s instructions for the instrument in use. Place clean or contaminated items on the appropriate side of the table.⁶⁶

RADIATION PROTECTION PRECAUTIONS IN THE MORGUE

Establish a triage station outside the control point, with a table for the remains containers and HRP and a technician equipped with gloves and a survey meter. The radiation technician should perform the triage. Survey each body. If a body reads greater than 100 millirem per hour with the probe 1 inch away, that body should be moved to a refrigeration unit at least 30 feet from the work area. This will prevent the morgue staff from exceeding their dose limits on the first few decedents; it will allow the morgue staff to consult with a health physicist and devise a special work plan; and if the source of the radiation is a mix of short-lived isotopes it will allow radioactive decay to decrease the dose rate.⁶⁶

Decedents that have no contamination can be transported to the regular morgue or to an uncontaminated field morgue for further processing. These are the only bodies that require a complete survey (front and back, inside the remains container, and inside the HRP).⁶⁶

Bodies that have measurable contamination below 100 millirem per hour at one inch should be sent to the field morgue. Prior to beginning processing the radiation safety officer should establish administrative limits on workers' doses based on the measured dose rates from the decedents and the number to be processed. This could be a total cumulative dose, such as 200 millirem for the entire operation; or if the number of expected decedents is not yet known it may be a limit like 25 millirem per decedent.⁶⁶

Workers in the morgue can minimize their doses by moving away from the work area when not doing something. This is an appropriate place for the "one person at the table at a time" rule. If available, use of remote cameras can reduce the number of people required at the scene.⁶⁶

If the decedent contains radioactive shrapnel, consider surgically removing it as early as practicable in the process without hampering the investigation. Do not touch the shrapnel with the hands. Place a specimen jar in a bucket. Remove the shrapnel with forceps and place it in the specimen jar. Place the bucket 30 feet or more from the work area.⁶⁶

After the forensic examination and victim identification process is complete decontaminate the decedent. This could be done in the final examination area, or the decedent could be moved to secondary decontamination area. Use of a dry vacuum with a HEPA filter is acceptable if none of the contaminants are volatile. This minimizes runoff. A spray and wet wipe is also effective. Washing with soap and water is a last resort. Decontaminate the body until it meets the FEMA standards.⁶⁶

Survey the decedent. Any area reading above the FEMA recommendations should be decontaminated again. Surgically remove any shrapnel. If the

decedent is still contaminated consider the contaminant internal contamination. Tag the decedent with the dose rate, distance of the probe, date, and time; and release the decedent to the funeral home.⁶⁶

Normally the medical examiner or coroner will return personal effects to the family unless they have some forensic value. In this case consider returning only personal effects that have monetary or sentimental value and are easily decontaminated (e.g. watches or rings).⁶⁶

AUTOPSIES

Autopsy of minimally radioactively contaminated cadavers does not require precautions other than contamination control and protective clothing. Autopsies of highly radioactive cadavers should be restricted to the absolute minimum. When measured dose rates near the surface of the body are in the range of 0.1-1.0 mGy/hr it may be advisable to split the task among several persons.⁶⁶

An autopsy normally entails extensive handling of internal organs by gloved hands. An autopsy may result in fairly high doses to the pathologist's hands. Also, an autopsy disrupts the circulatory system, so an embalmer will have to work longer in close proximity to a body that has been subjected to an autopsy. Do not perform an autopsy if there is internal contamination, unless it is absolutely necessary.⁶⁶

PROCEDURES FOR RADIOACTIVELY CONTAMINATED DECEDENTS IN THE FUNERAL HOME

A person exposed to a radioactive source does not become radioactive. No special precautions are required for handling the remains of persons killed by exposure to an external radiation source.⁶⁶

If radioactive contamination is suspected and the medical examiner cannot certify that he has complied with CDC's guidelines, the funeral director should consider rejecting the decedent. If this is not feasible, find a radiation technician who can conduct a survey of the body and provide dose rate information. Do not attempt to embalm or work near a decedent with an unknown dose rate.⁶⁶

Recommend to the family that they bury the decedent immediately and conduct a memorial service without a viewing. If this is not acceptable for emotional, cultural, or religious reasons then embalming is required. The funeral director will have to estimate the exposures to the person performing the embalming and to the family members. Medical examiners should have provided a tag indicating the dose rate from the decedent and the distance from which it was measured. Dose rate decreases with the square of the distance, so encourage family members and friends to minimize their time next to the decedent.⁶⁶

Use the standard time, distance, shielding methods of protecting family members to minimize their exposure. Shielding may be difficult, however, time and distance can be easily controlled and enforced. Think of the human remains as a point source and apply the time and distance accordingly. ¹⁵

Avoid the use of adjectives like “safe” or “dangerous.” Compare the estimated dose to a familiar source like chest radiographs, airline flights, or dental radiographs. ⁶⁶

The embalmer can use the canula to inject fluid and drain the blood. No special precautions are required for this step. Do not perform the aspiration step with the trocar. Inject cavity fluid without first aspirating the lungs and gastrointestinal tract. ⁶⁶

Cremation Do not cremate a decedent whose body contains man-made radioactive material. Whether cremation is allowed depends on what type and amount of radioactive materials are released to the environment by incineration or by disposal of ashes. When a decedent is cremated all volatile materials escape up the refractory. After completion of cremation the crematory staff will manually pulverize the ashes before returning the remains to family members. Non-volatile radioactive material poses an airborne respiratory hazard to the crematory staff plus a risk of contaminating the crematorium. ^{17, 66}

Shrapnel or brachytherapy seeds will not be destroyed in the process of cremation. If cremation is desired and the source is shrapnel, brachytherapy seeds, or some other discrete source, surgically remove it. ⁶⁶

Burial Burial is typically not an issue unless there are extremely long-lived radionuclides present that may ultimately find their way into the environment in concentrations that exceed regulatory. Select a burial container that will delay the release to the environment as long as practicable. Wooden caskets are not sealed. Metal caskets have a seal that will release pressure from inside the casket, but will retard the entry of ground water. Place the body in a metal casket, not a wooden one, and place the casket in a concrete vault lined with plastic. Use the type that has a lid with a butyl compound gasket with a tongue in groove seal (Figure 14). In the cemetery, place the lid on the vault above ground where it can be inspected for a tight fit before lowering into the grave. ^{17, 66}

X. ADHS RESPONSE

The Arizona Department of Health Services Health Emergency Operations Center (HEOC) would be activated in the event of an RDD to coordinate the public health response with the State Emergency Operations Center (SEOC)

Good communication between Public Health Professionals and the on-scene response team is critical.^R

SITUATION AND ASSUMPTIONS

- In the event of a radiological incident, the Arizona Radiation Regulatory Agency (ARRA) and the Arizona Division of Emergency Management are the primary state agencies. ADHS serves as a supporting agency.
- Currently, the ADHS State Laboratory does not accept radiological samples. All radiological samples will be tested by the ARRA Laboratory or an appropriate Federal agency. For example, Environmental Samples (EPA), Animals (USDA), Food and Animal Feed (DHHS)
- Other sources of radiological screening include the 91st Civil support Team, local HazMat teams and the Metropolitan Medical Response System (MMRS).

Concept of Operations

The response of the Arizona Department of Health Services to a radiological incident closely resembles that for an incident at the Palo Verde Nuclear Generating Station.

Under this plan, the Department will utilize its incident command system called the Public Health Incident Management System (PHIMS) to manage the incident. The ADHS PHIMS response system is divided into four functional areas: Operations, Planning, Logistics and Finance.

The Operations Section functions specific to this incident will include the following:

- Technical advice on safe food and water supply and use issues
- Drafting of environmental and public health messages for the public and healthcare practitioners.
- Update messages as necessary for the ADHS 24-hour recorded Information Line
- Tracking of epidemiological data
- Support of local health departments for resources and staff time

Plans

The Planning Section will cover the following activities:

- Creation of the PHIMS Chart
- Generation of the Incident Action Plan
- Collection of information and compilation of Situation Reports
- Preparation of Governor's Reports
- Coordination of the creation of GIS maps as needed with Logistics

Logistics

The Logistics Section will handle the following:

- Blast-faxing and other alerts and notifications through the HAN and EMS System
- Tracking Department volunteer resources
- Obtaining the webpage hits to ADHS information pages
- Obtaining the number of callers to the 24-hour recorded Information line
- Setting up the Health Emergency Operations Center (HEOC)

Finance

The Finance Section will perform the following:

- Tracking hours spent on radiological response activities
- Give assistance with budgeting for the response
- Obtain contracts and procure needed items.

INTERNAL ORGANIZATIONAL ROLES AND RESPONSIBILITIES

The Arizona Department of Health Services (ADHS) will:

- Support the local health departments and broker resources as much as possible including hospital space and emergency medical services.
- Provide a Public Information Officer to craft (in conjunction with the local health departments) various health messages for the State Emergency Operations Center's Joint Information Center (JIC)
- Provide guidance for the distribution of decorporating drugs such as potassium iodide (KI) from the local health department
- Coordinate with the Centers for Disease Control and Prevention and the Federal Advisory Team"
- Order the Strategic National Stockpile if needed (See ADHS SNS Plan)
- Work with the CDC, ATSDR and local health departments to put together a registry*

* A registry is comprised of the contact information of persons potentially exposed to radiation/explosion and will be assembled with the collaboration of CDC, ATSDR, ADHS and the local health department. The purpose of the registry is for subsequent dose assessments; possibly providing the

registrants educational material regarding their exposures, possible medical follow-up should that become necessary and for addressing possible long-term health effects. The registry is comprised of a one-page survey instrument. CDC/ASTDR will provide the survey instrument and the personnel to assist ADHS and the local health department in this endeavor. A copy of the survey form is included in the Appendix C of this plan.

The PHIMS Environmental Health Group (under Operations) will:

- Provide public health information related to public health issues such as sheltering-in-place, decontamination of foodstuffs*
- Give guidance and recommendations on food storage and food safety to the State Prison kitchens as well as Assisted Living and Group Homes.
- Inspect various shelters for sanitation and cleanliness
- Support (if needed) the local health departments and the Arizona Department of Agriculture in utilizing the embargo authority, conducting inspections and gathering samples**
- Provide support to the Arizona Department of Environmental Quality and the local health departments to advise on safe drinking water and community water systems

** Responsibility for the radiation testing of all exposed food lies with the Arizona Radiation Regulatory Agency (ARRA) or their Federal designee and that for general food safety is delegated through agreements to the local Environmental Services Departments by the Arizona Department of Health Services. In addition to radiological contamination there may be more traditional food safety circumstances to contend with such as proper refrigeration of foods in the event of a power outage.

The responsibility of the local County Environmental Services Department for safe foodstuffs includes produce warehouses, food processing, outdoor settings, (special events) school cafeterias and retail settings (grocery stores, convenience stores). The responsibility for the safety of eggs, dairy, raw meats, grains and fresh fruits and vegetables (in the field or on the farm) is overseen by the Arizona Department of Agriculture.

EXTERNAL ORGANIZATIONAL ROLES AND RESPONSIBILITIES

Local Health Department

- With consultation from ARRA and ADHS is responsible for the distribution of KI to the public
- Responsible for the safety of foods from the produce warehousing stage to the retail stage.

Arizona Radiological Regulatory Agency (ARRA)

- Oversees trained volunteers to conduct field sampling and radiological screening of persons

- Performs radiological analysis of water, soil, vegetation, milk and limited clinical samples either in their mobile laboratory or at their permanent facility
- Provides a liaison at the State Emergency Operations Center
- Provides a contact for the Joint Information Center (JIC)

Arizona Department of Agriculture

- Responsible for the integrity/safety of milk, eggs, meat, grain and fresh fruits and vegetables in the affected area.
- Responsible for establishing check points to ensure food that is being transported meets food safety standards

STATE RESPONSE

This plan follows the information written in the State Emergency Response and Recovery Plan (SERRP) Version 1.0, Emergency Support Function (ESF) #18 *Nuclear Power Radiological Emergency Preparedness Annex*.

Primary Agencies:

- State - Arizona Division of Emergency Management, Arizona Radiation Regulatory Agency
- County - County Department of Emergency Management
- Private - Arizona Public Service Company

For detailed information regarding the roles and responsibilities of State and Local agencies, this ESF refers to: [The Offsite Emergency Response Plan for Palo Verde Nuclear Generating Station](#) for nuclear and radiological events.

FEDERAL RESPONSE

At the time of this version of the ADHS Radiological Response Plan, a significant shift involving the presentation and format of the National Response Plan (NRP) is currently underway and receiving public comment. Under the new plan name, the Federal Response Framework (NRF) the Federal Response for a nuclear/radiological event is guided primarily by the NRF and its Nuclear/Radiological Incident Annex.

<http://www.fema.gov/emergency/nrf/mainindex.htm>

There are several Federal Assets whose services and expertise can be requested by the Coordinating Agency or Department of Homeland Security. One of them is the Advisory Team for Environment, Food and Health

The Advisory Team includes representatives from the Department of Homeland Security (DHS), Environmental Protection Agency, the Department of Agriculture,

the Food and Drug Administration, the Centers for Disease Control and Prevention and other Federal agencies. The Advisory Team develops coordinated advice and recommendations for DHS, the Unified Coordination Group, the coordinating agency and State, tribal and local governments concerning environmental, food health and animal health matters. The Advisory Team selects a chair for the Team.

The Advisory Team provides recommendations in matters related to the following:

- Environmental assessments (field monitoring) required for developing recommendations with advice from State, tribal and local governments and/or the FRMAC senior monitoring Manager.
- Protective Action Guides and their application to the emergency
- PARs using data and assessment from the FRMAC
- Protective actions to prevent or minimize contamination of milk, food and water and to prevent or minimize exposure through ingestion.
- Recommendations for minimizing losses of agricultural resources from radiation effects
- Availability of food, animal feed and water supply inspection programs to assure wholesomeness
- Relocation, reentry and other radiation protection measures prior to recovery
- Recommendations for recovery, return and cleanup issues
- Health and safety advice or information for the public and for workers
- Estimated effects or radioactive releases on human health and the environment
- Other matters, as requested by the coordinating agency.

(pgs. NUC-19-20, from the July 2007 Draft Nuclear and Radiological Incident Annex))

XII. RADIATION RESPONSE RESOURCES

This information was extracted from Nuclear News, September 2006, Resources For Nuclear And Radiation Disaster Response.

GENERAL

A number of organizations exist that can respond to radiation crises initiated by malevolent forces or resulting from an accident or the mismanagement of domestic radioactive sources. These organizations are operated by various federal and state government agencies and the military, including the states' National Guard Weapons of Mass Destruction–Civil Support Teams (WMDCST). It would be exceedingly helpful for localities and their first responders to know how the deployment of these many assets would cascade from one agency to another or dovetail between agencies to produce a coordinated effort. Deployment of some organizations is clear, dictated by the ownership of the nuclear/radiological material or the location of the incident (domestic or overseas). In other cases, particularly on home soil, the agency initially responding (after local first responders) is not so clear. Training, drills, and exercises are ways to test the relationships and identify any issues needing resolution or improvement.

Overall, radiological/nuclear emergency responses include these basic functions:

- Measuring and tracking radioactivity in the affected environment, especially if it is airborne. This includes the use of computer modeling in the early stages of the emergency.
- Measuring radiation levels in the affected area.
- Locating, securing, and/or disarming sources of radiation, e.g., lost medical or industrial sources or improvised nuclear or radiological dispersal devices.
- Providing information about the above to mitigate human health consequences.
- Securing and remediating the affected area.
- Treating affected personnel, if necessary.

Nuclear weapon incidents or accidents will involve a joint Department of Energy and Department of Defense (DOD) response. Local responders and state agencies, who always have the primary responsibility for the protection of the public, will also be involved.

This article summarizes the functions of the major response groups, with Fig. 1 and Table I providing a brief orientation for the reader. A section on the civilian medical response highlights problems in this area, and a brief final section derived from extant information about large-scale drills discusses some concerns about coordination among agencies.

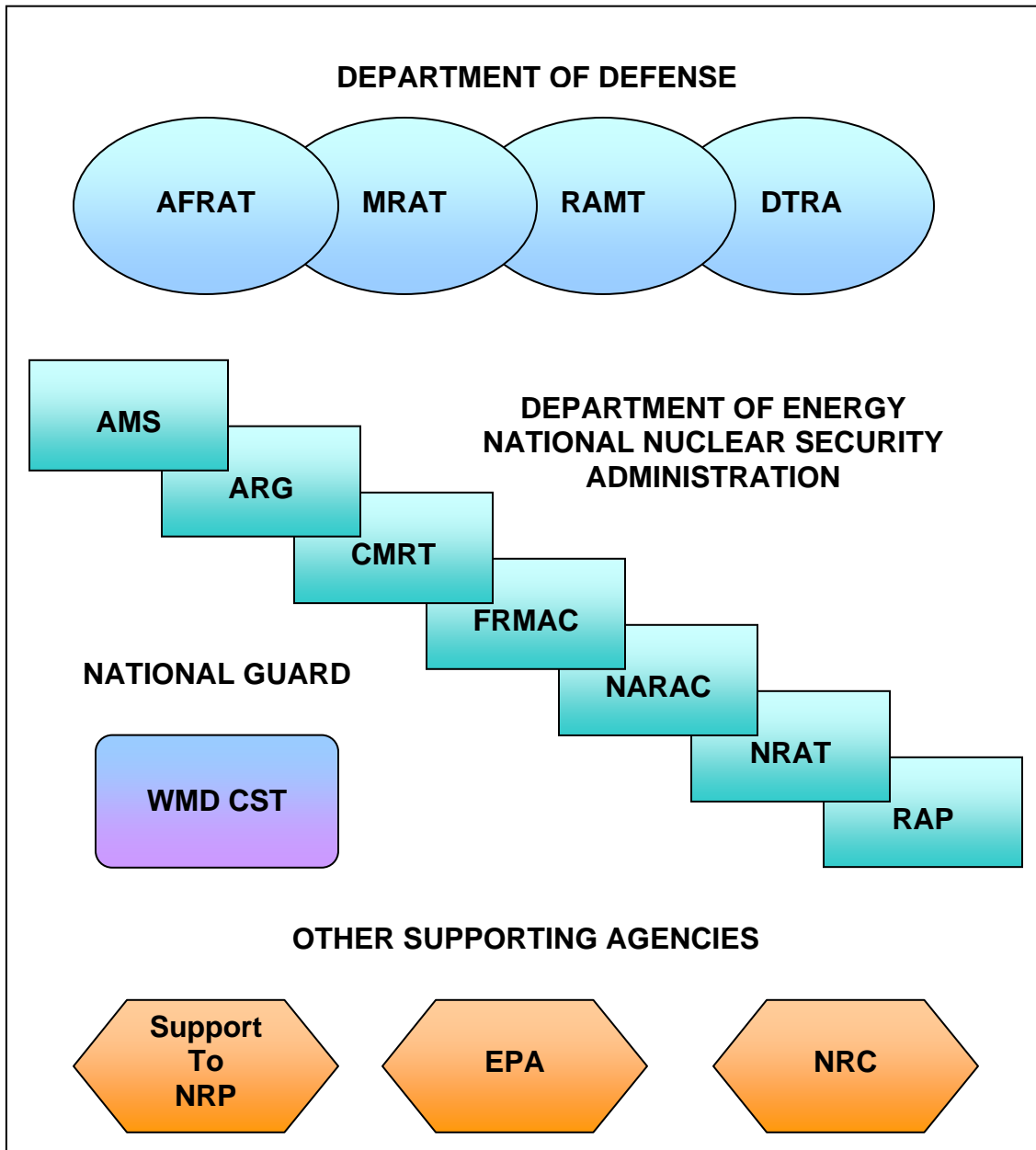


Figure XIII-1. Major U.S. civilian and military radiological response programs. Most programs are DOE/NNSA assets; military assets may contribute as needed or operate in strictly military crises. The NRC responds to incidents involving its licensees and those of agreement states, and the EPA participates during the crises and afterward, when remediation is being carried out. The National Guard is considered a state (not federal) asset. The civilian medical response is not indicated, but is crucial to the overall response effort.

THE MILITARY RESPONSE

A military response will involve the DOD and may include the Defense Threat Reduction Agency (DTRA), which coordinates DOD responders to a nuclear/radiological incident. The DOD assists local, state, tribal, and federal civil agencies. The National Response Plan (NRP), which is available on the Department of Homeland Security's (DHS) Web site, establishes the interagency relationships for DHS's coordination of domestic incident management emergencies.

Under the NRP, the federal responders, both civilian and military, have the lead in assessing the extent of the radiological release in support of the local Incident Commander, who manages operations at the incident site, develops strategies and tactics, and allocates resources, and a primary mitigation role in domestic incidents.

The National Guard CSTs are available through the states to assess the seriousness of radiological accidents, to predict the consequences, and to assist the Incident Commander in the management of the consequences.

Again, this expertise is intended as a resource for local officials. The DTRA Operations Center serves as a single point of contact and communications hub in the event of an incident involving the DOD. A global radiological/nuclear field response is provided by the Air Force Radiation Assessment Team (AFRAT), which is based in San Antonio, Texas. Its mission is to deliver radiological risk assessment to assist in the recovery of the affected area. For example, AFRAT provides hazard assessment for deployed troops facing possible nuclear or radiological threats. But it can also respond to a domestic or overseas terrorist attack on nuclear-use facilities, a nuclear reactor accident, or a radiological dispersal device (RDD), or "dirty bomb," incident. AFRAT is a 40-person mobile radiological response asset that includes a laboratory with the capability to sample air, water, soil, and foodstuffs. AFRAT can determine whether personnel have ingested or inhaled radioactive material (bioassay analysis), provide a site map indicating the locations of radioactive contamination, and implement decontamination and radioactive waste management operations.

Worldwide medical assistance is provided by the U.S. Army through its Radiological Advisory Medical Team (RAMT), headquartered at Walter Reed Army Medical Center in Washington, D.C. This organization provides medical information to a combat commander, but assistance to nonmilitary response teams and local hospitals is also mandated, both in peace and in wartime. RAMT capabilities include the radiological scanning and decontamination of 20 litter patients per hour, the scanning of 200 ambulatory patients per hour, and database tracking of patients.

The Medical Radiobiology Advisory Team (MRAT) is operated by the Armed Forces Radiobiology Research Institute (AFRRI), in Bethesda, Md. Activated by

DTRA, MRAT provides radiological and medical expertise to military commanders and medical providers. This includes advice concerning wound decontamination, the use of radioprotective drugs, and personnel decontamination. MRAT is a small team consisting of about 14 individuals with expertise in medicine, health physics, nuclear engineering, and radiobiology. Additional specialized teams may be available from both the U.S. Army and the U.S. Navy to assist in radiological/nuclear emergencies.

NON-DOD FEDERAL RESPONSE

The primary civilian government agencies responding to radiological incidents include the National Nuclear Security Administration (NNSA), which is a semiautonomous agency within the DOE, the Environmental Protection Agency (EPA), the Nuclear Regulatory Commission, the Department of Health and Human Services, the Department of Agriculture, and others.

One of the best-known civilian response organizations is the Radiological Assistance Program (RAP), which is administered by the NNSA. RAP does not take control of the radiological incident, but rather supports the local responders and reports to the Incident Commander. RAP will leave the scene once adequate resources are available and its assistance is no longer required. The main mission of RAP is to provide information or deployable assets (DOE measurement equipment and personnel) in order to assess and mitigate a radiological incident. RAP teams are organized across the nation in eight regions, and there is also a team for the national capital region. They can be on site within six hours of notification and are probably the most easily accessible radiological responders. They respond to telephone inquiries (see Table XIII-2), often resolving many situations via this route of communication. If radiological materials become airborne, two NNSA response assets can be brought into operation. One of these, the National Atmospheric Release Advisory Center (NARAC), uses current meteorological data, land topography, computer codes, and incident time and location to predict the dispersion of airborne radiological materials. The results, continually refined until the threat is fully assessed, are also available via the Internet. This information is a “first cut” decision-making tool that can be used to geographically deploy responders efficiently and effectively.

The other airborne assessment tool is the NNSA’s Aerial Measuring System (AMS), which can be initiated by RAP. Nellis Air Force Base, in Las Vegas, Nev., and Andrews Air Force Base, in Washington, D.C., are the locations for the fixed- and rotarywing aircraft used in this program. The radiological detectors mounted on the craft provide real-time information about ground contamination. The mission of AMS includes assessments of the location, size, dispersion pattern, radioisotope content, and radiation intensity of the contamination on the ground. The DOE’s radiological triage capability can be requested from DOE headquarters in Washington, D.C., or through a RAP team member, to identify unknown radiation sources and to advise about possible hazards.

The DOE assists on-site responders and other NNSA assets by interpreting the results of gamma-spectrographic analysis. This program supports other federal and state agencies whose personnel may search out radioactivity as a part of their jobs, such as the Federal Bureau of Investigation. Another NNSA radiological response asset is the Radiation Emergency Assistance Center/Training Site (REAC/TS), which provides medical information, medical information as of July 2004. These missions and capabilities could be augmented.

Table XIII-1. Summary Of Major U.S. Nuclear/Radiological Response Assets And Functions

Responder	Main Mission	Parent Agency	Contingent and/or Equipment*
AFRAT	Reactors and weapons accidents; terrorist use of RDD or nuclear weapon; measurement of radiation; assessment of radiation hazard	USAF DOD	43 persons; field lab; radiation detectors
RAMT	Radiological medical support and decontamination; assist local hospitals	USAR DOD	Multiple radiation detectors and software for radiation analyses and patient dosimetry
MRAT	Medical expertise post-nuclear accident or detonation	AFRRI DTRA JTAC State Dept	13 persons + DOD "reachback" (in-office) assistants; on-site advice to attending physicians
RAP	First responder radiation assistance for general public and environment; assist other government agencies to detect, identify, and analyze nuclear radioactive materials	DOE NNSA	8 regions nationwide plus team in National Capital Region; 3 teams/region; 9 members/team; multiple radiation detectors; mitigative advice; public info support
NARAC	Real-time predictions of atmospheric transport and dispersion of radioactive material	DOE NNSA	Computer-produced atmospheric transport and dispersion calculations
AMS	Radiation mapping around incident scene	DOE NNSA	Fixed-wing and rotary aircraft
REAC/TS	Medical consultation/training concerning radiation accidents	DOE NNSA	24-hour service; deployable team of health professionals; patient care at REAC/TS
ARG	Nuclear weapon accident response; advise DoD ordnance disposal teams	DOE NNSA	Specialized equipment and personnel to advise on U.S. nuclear weapons recovery, transport, disposal, and safety
FRMAC	Coordinates and provides federal assistance in response to major radiological incidents. Response includes offsite assistance when requested by federal, state, local, and tribal authorities	DOE NNSA	Coordinates federal, state, and local monitoring activities; CMRT I, II, and III teams with increasing capabilities deployed, if needed; supplies include communications, living quarters, and power generation
National Guard WMD-CST	Support of civil authorities at a domestic chemical, biological, radiological, nuclear, and high-explosive incident. Will identify hazardous agent substance, assess current and future consequences, advise on response measures, and assist civil responders in affected state(s)	USAF USAR National Guard DOD	22 member teams; 55 teams planned; vehicle and air deployment for rapid domestic response; assigned to governor of affected state; tactical/communications vehicles and analytical lab; medical and radiation survey teams

The Joint Technical Augmentation Cell (JTAC) plans and integrates overseas WMD exercises. It is a part of the Joint Task Force Civil Support (JTF-CS)

operation that plans and integrates DOD support to the federal agency designated to lead a WMD consequence management operation. JTF-CS handles domestic incidents, while JTAC is involved in nondomestic incidents. RAP will leave the scene once adequate resources are available and its assistance is no longer required.

The main mission of RAP is to provide information or deployable assets (DOE measurement equipment and personnel) in order to assess and mitigate a radiological incident. RAP teams are organized across the nation in eight regions, and there is also a team for the national capital region. They can be on site within six hours of notification and are probably the most easily accessible radiological responders. They respond to telephone inquiries (see Table II), often resolving many situations via this route of communication. If radiological materials become airborne, two NNSA response assets can be brought into operation. One of these, the National Atmospheric Release Advisory Center (NARAC), uses current meteorological data, land topography, computer codes, and incident time and location to predict the dispersion of airborne radiological materials.

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The DOE’s radiological triage capability can be requested from DOE headquarters in Washington, D.C., or through a RAP team member, to identify unknown radiation sources and to advise about possible hazards. The DOE assists on-site responders and other NNSA assets by interpreting the results of gamma-spectrographic analysis. This program supports other federal and state agencies whose personnel may search out radioactivity as a part of their jobs, such as the Federal Bureau of Investigation. Another NNSA radiological response asset is the Radiation Emergency Assistance Center/Training Site (REAC/TS), which provides medical information, medical personnel, and patient care in the event of a radiological accident. REAC/TS has a domestic and international mission by virtue of its designation as a World Health Organization Collaboration Center for Radiation Emergency Assistance. It maintains a radiological laboratory and radiation dose assessment and training facilities in Oak Ridge, Tenn.

Responses to incidents involving nuclear weapons under DoD or DOE custody can involve the DOE's Accident Response Group (ARG), whose expertise includes weapons designers, radiation health professionals, and nuclear scientists, so that knowledge of all weapons in the U.S. stockpile is at hand. Advice is provided to federal agency explosive ordnance disposal teams to identify weapon components, render weapons safe, and work together to package, transport, store, and dispose of damaged weapons/nuclear material. The DOE maintains a number of other specialized teams to respond in support of the Department of Justice and other federal and state agencies when terrorist-related radiological/nuclear material is involved. These teams are activated by contacting the Emergency Operations Center at DOE headquarters or by going through one of the RAP teams.

The Nuclear Regulatory Commission will respond to terrorist and emergency incidents at the nuclear, industrial, and medical facilities it licenses. Some states, designated "agreement states," are authorized by the NRC to regulate their own licensees using state versions of NRC regulations. The NRC will also respond to terrorist actions at agreement state facilities. The NRC acts as a "coordinating agency" when responding to incidents involving its licensees or agreement states and as a "cooperating agency" under all other circumstances. This agency can provide incident assessments and probable consequences, public protective measures, and oversight of the affected licensee.

AUGMENTED CIVIL RESPONSE

The National Guard has been organized into 55 jointly staffed (Army and Air Force) Weapons of Mass Destruction-Civil Support Teams (WMD-CST). Their role is to support civil authorities (Governor of Arizona) by identifying a WMD, assessing the immediate and future hazard, advising on countermeasures, and determining whether additional expertise is needed. Their role includes assistance to local civil responders.

A CST advance party can be en route to a scene within 90 minutes of an alert. Follow-up team members can deploy within three hours. Transport by rotary- or fixed wing aircraft is authorized. Equipment assigned to CSTs includes SUV-type vehicles, a mobile analytical laboratory, and communications vans. Each of the CSTs has 22 full-time team members and a number of response vehicles, including trailers totaling about 40 tons, and can be airlifted by military craft.

COORDINATING THE RESPONSE EFFORT

The coordination effort that is to occur among government agencies during a devastating or potentially devastating "Incident of National Significance" is defined in the DHS's National Incident Management System. Lesser incidents will not require as extensive a response.

Coordination among federal and state agencies during the emergency phase of a

nuclear/radiological incident may be handled by the NNSA's Consequence Management Planning Team. This is an advance component of the Federal Radiological Monitoring and Assessment Center (FRMAC), which is a response asset implemented in sequential phases. The origin of the FRMAC can be traced back to the nuclear power plant accident at Three Mile Island in 1979, when it was realized that a federal radiological emergency response plan was called for. The mission of the FRMAC, which is composed of representatives from several federal agencies and state and local radiological response agencies, is to coordinate federal and state/local radiological monitoring and assessment activities. It is initiated through a request to the DOE by an affected federal or state government agency. If the emergency involves a nuclear weapon, either the DOE or the DOD is the lead agency (whichever organization had custody of the weapon at the time of the incident/accident). If an RDD is the issue, the FBI becomes the lead agency representing the Department of Justice. An accident at a nuclear power plant will put the NRC in the lead role. Monitoring and situation assessment data are passed to state personnel, as well as to the federal agency that has the lead under the NRP. State personnel and the lead agency are both considered FRMAC "customers."

FRMAC will activate Consequence Management Response Teams (CMRT) in a phased manner. An initial CMRT can respond within four hours after notification. Reliable communications links are set up, and coordinated measurements, analysis, and consequence management of the radiological situation are implemented. This capability can be expanded to an around-the-clock response by setting up additional voice, video, and data links, enhancing radiological monitoring and environmental sampling, and augmenting expertise with additional RAP personnel. Additional services of the CMRT are on-site accommodation services, photo/video specialists, and data control expertise for any high-level crises. Once the incident enters the recovery phase, the EPA takes over the management of FRMAC from the DOE by mutual agreement. For a summary of the timeline for deployment of CMRTs involved with airborne radioactive materials, see Figure XIII-2.

FRMAC activation parameters are broad. A nuclear detonation, terrorist threat, or radiation release from a nuclear reactor are FRMAC considerations. If the incident requires an accelerated national response, the NRP establishes such a strategy in its Catastrophic Incident Annex (NRP-CIA), which would be brought to bear under conditions of mass casualties or damage that severely impinges on the infrastructure, economy, environment, or functions of government. The NRP-CIA is activated only by the secretary of Homeland Security. The following local services are to be augmented by NRP-CIA through so-called "push packages": hospital care for mass casualties, search and rescue capabilities, decontamination capabilities, mental and public health expertise, fatality management, medical instrument and pharmaceutical supplies, and dispersal of public information.

CIVILIAN MEDICAL RESPONSE

It is generally conceded that even if all the government assets outlined above are properly implemented, perceived or real radiation exposures from a WMD or a nuclear detonation will likely present overwhelming challenges to first responders and local medical personnel. If a 1-kiloton nuclear device is detonated in an urban environment, “7000 prompt casualties may occur, along with 20 000 victims requiring intensive care.”

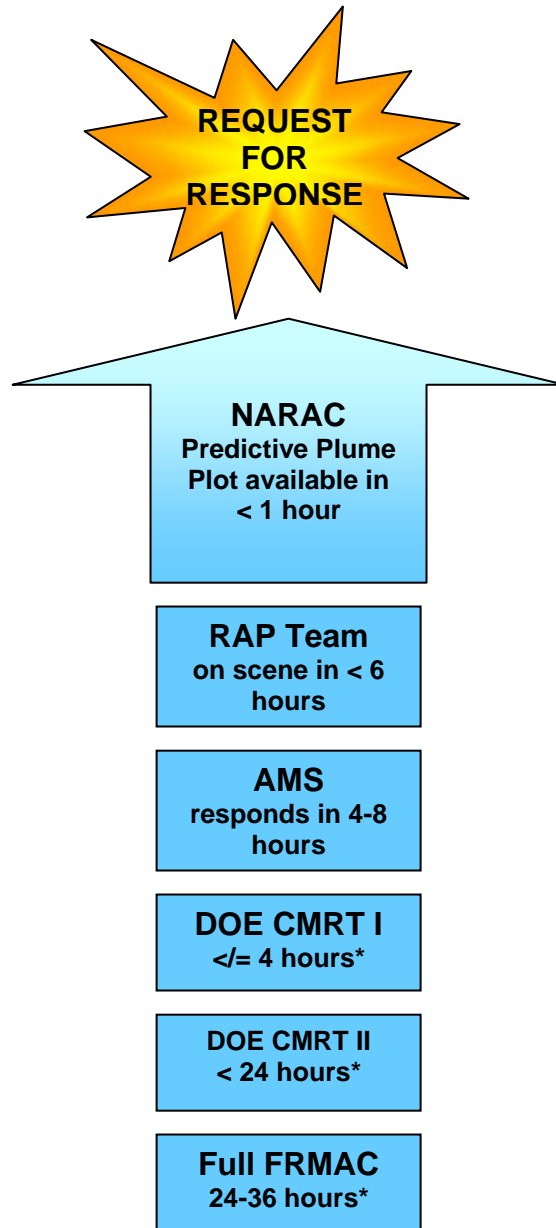


Figure XIII-2. Typical timeline for deployment of DOE emergency response components.
*after activation, not including travel time.

There are two basic needs for a successful medical response: (1) sufficient and adequate radiation detection equipment for first responders and medical staff,

and (2) expertise in the treatment of radiation-related casualties, including those with internal radionuclide contamination. It is not clear at this time that either need has been met in the United States. First responders are being equipped with belt-type devices that alarm when radiation dose rates are high or when a preset cumulative dose level has been reached. Wide distribution of these devices is ongoing but not yet fully achieved. The identification of contaminating radionuclides via the use of portable spectrometers is of great assistance in the treatment of affected patients.

In Arizona most first responders and hospitals, however, are in the process of receiving and being trained on their Ludlum Responder equipment. It is postulated that patients of a nuclear or radiological incident would begin arriving at hospitals relatively quickly compared with off-site federal or military responders, thus making the collection of radionuclide data even more relevant. Physicians who are triaging victims must be able to recognize acute radiation sickness and have knowledge of the few drugs that can be administered to block radioactivity uptake, e.g., potassium iodide in the case of radioactive iodine, or to accelerate the elimination of internalized radioactivity, e.g., DTPA in the case of plutonium, and Prussian Blue in the case of cesium. This requires training, and the radiological disaster training of medical personnel must compete with their continuing education needs.

The Federal Government has resources to assist the civilian medical response to large-scale disasters. Under the NRP, the Department of Health and Human Services (DHHS) coordinates the Emergency Support Function, providing for public health and medical services. DHHS may deploy assets from the U.S. Public Health Service Commissioned Corps and the Strategic National Stockpile of drugs. An important supporting organization is the National Disaster Medical System (NDMS), which is a coordinated partnership of DHS, DHHS, DOD, and the Department of Veterans Affairs.

The mission of the NDMS is to design, develop, and maintain a national capability to deliver medical care to both responders and victims of a domestic disaster. The NDMS provides on-site medical care, patient transport from the disaster, and medical care at preassigned hospitals outside the affected area. The response capability of the NDMS includes Disaster Medical Assistance Teams to deal with on-site medical triage and treatment, Disaster Mortuary Operational Teams to handle mortuary procedures, National Nursing Response Teams to provide nursing services where feasible, National Pharmacy Response Teams, and Veterinary Medical Assistance Teams. Participation in the NDMS by hospitals is achieved and maintained by federal coordinating centers that perform drills, develop emergency plans, and design patient reception, transport, and communication plans. Members of the NDMS teams are civilian volunteers. The Medical Reserve Corps, which is coordinated by the Office of U.S. Surgeon General, is another network of local volunteer medical and public health professionals.

XIII. ARIZONA STATE RADIATION RESPONSE RESOURCES

Arizona Radiation Regulatory Administration (ARRA)

<http://www.arra.state.az.us/>

602-255-4845

Arizona Department of Emergency Management (ADEM)

<http://www.azdema.gov/>

(800) 411-2336

ARIZONA EMERGENCY RESPONSE COMMISSION

azserc@azdema.gov

(602) 231-6346

Arizona Department of Environmental Quality (ADEQ)

<http://www.azdeq.gov/function/about/contact.html>

(800) 234-5677

Arizona Department of Health Services (ADHS)

<http://www.azdhs.gov/>

(602) 542-1000

Bureau of Emergency Preparedness and Response

(602) 364-3289

ARIZONA 211 - just pick up the phone and dial 211

Arizona 2-1-1 was created Online to help you easily find resources from child care, jobs, health care, and insurance - **to State and local emergency bulletins and alerts that are vital in times of disaster or emergency.**

Arizona 2-1-1 Online was developed in partnership with government, tribal, non-profit and community groups to help you find the resources and information you need."

XIV. 24 HOUR FEDERAL RADIATION RESPONSE RESOURCES

OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION

For more than 25 years, the Oak Ridge Institute for Science and Education (ORISE) has provided the U.S. Department of Energy (DOE) with a comprehensive capability to respond effectively to medical emergencies involving radiological or nuclear materials. ^C

An Emergency Response Asset

ORISE's Radiation Emergency Assistance Center/Training Site (REAC/TS) is a deployable DOE National Nuclear Security Agency (NNSA) asset, on call 24/7 to offer its expertise on managing the medical component of a radiation incident. Additionally: ^C

- REAC/TS is identified in Section 501 of the Homeland Security Act of 2002 as a response organization and member of DOE's Nuclear Incident Response Team.
- REAC/TS is identified in DOE Order 5530 as the organization that provides medical assistance to DOE's Accident Response Group and the Federal Radiological Monitoring and Assessment Center (FRMAC).

Personnel

REAC/TS has developed an interdisciplinary radiation emergency medical response approach that integrates medicine with health physics. This enables rapid dose assessment, radiological and medical triage, diagnosis, and medical management during a radiation emergency. ^C

REAC/TS maintains specialized response teams to ensure our readiness to respond. Each team consists of a physician, nurse/paramedic, and a health physicist—all cross-trained in the details of managing a radiation emergency. Our response teams are equipped with state-of-the-art medical equipment that can be transported to a site or used in our unique facility in Oak Ridge, Tenn., located adjacent to the Methodist Medical Center. The staff are equipped to perform at REAC/TS: ^C

- medical and radiological triage
- decontamination
- diethylenetriaminepentaacetic acid (DTPA) and Prussian Blue therapy for specific radiological materials
- diagnostic and prognostic assessments of radiation-induced injuries
- biological and radiological dose estimates by methods that include cytogenetic analysis, bioassay, and in vivo counting.

The ORISE website is located at
<http://orise.orau.gov/reacts/rad-incident-response.htm>

FEDERAL RESPONSE EMERGENCY RADIOLOGICAL PLAN (FRERP)

The FRERP assigns to DOE the responsibility to set up and initially manage a FRMAC. DOE's/NNSA's contribution to the FRMAC is the Consequence Management Response Team (CMRT). The CMRT draws from the NNSA Emergency Response Assets and becomes the NNSA coordination element for the FRMAC.^L

Mission The FRMAC mission is to coordinate and manage all Federal radiological monitoring and assessment activities during major radiological emergencies within the United States in support of state, local and Tribal governments through the Lead Federal Agency (LFA). The LFA is the agency that is responsible for leading and coordinating all aspects of the Federal response.^L

Steps in the FRMAC Response

- NNSA may respond to a state or LFA request for assistance by deploying a Radiological Assistance Program (RAP) team. If the situation requires more assistance than RAP can provide, upon request NNSA will activate a FRMAC.
- NNSA uses a phased approach to deploy NNSA elements of the FRMAC. The NNSA response begins with deployment of a CMRT
 - Phase I team consisting of technical and management personnel who depart from Las Vegas within four hours of notification, and can reach any location in the United States normally within 6-10 hours.
 - This team meets with the LFA and state to review what has occurred and how serious it is, establishes the FRMAC, what FRMAC can do to help and how to do it, and to identify the best location for a working FRMAC.
 - The team initiates all technical components of a FRMAC response, and is reinforced soon after by DOE (CMRT Phase II) and interagency personnel who enable the FRMAC to operate around the clock.
 - If required, the full interagency FRMAC can be operational in 24-36 hours after the LFA or state has asked for help.
- A FRMAC's size is tailored to the event and may consist of as few as 60 or as many as 500 people, depending upon the needs of the emergency situation.^L

FRMAC Activities Include:

- Coordinating Federal offsite radiological environmental monitoring and assessment activities

- Maintaining technical liaison with state, local and Tribal governments
- Maintaining a common set of all offsite radiological monitoring data
- Providing monitoring data and interpretations to the LFA, state, local and Tribal governments.

The initial monitoring is focused on the protection of the public and the investigation of the type, amount, and extent of the radiological release. Monitoring continues until all of the area where radioactivity was released is fully evaluated and the effects are known. Any monitoring results that show an immediate threat to public health are promptly reported. All raw data coming into the FRMAC from field teams is quickly reviewed and given to the LFA and state representatives. Then the raw data is processed, evaluated and summarized, and approved by the FRMAC Director for distribution outside the FRMAC. This evaluated technical information is given officially to the LFA and state at the same time.^L

At some mutually agreeable time following the emergency phase, NNSA will transfer responsibility of managing the FRMAC to the Environmental Protection Agency. NNSA and other Federal agencies will continue to provide resources for as long as is necessary to complete the Federal response to the emergency.^L

FRMAC Products

The FRMAC will present the environmental radiological data to the LFA, state and local authorities in a usable format and in a perspective understandable by managers and decision-makers.^L

FRMAC products include:

- Predictive plots of plume dispersion and dose rates prepared using ARAC
- Aerial survey data provided by AMS

The FRMAC website is located at

<http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/default.htm>

EPA'S RADIOLOGICAL EMERGENCY RESPONSE TEAM (RERT),

EPA has had radiological responsibilities since the Agency's creation in 1970. In 1975, these responsibilities were expanded when the General Services Administration first outlined the various federal agencies' responsibilities for radiological emergency response planning.

Since then, EPA's radiological emergency response role & responsibilities have expanded.

Some of EPA's responsibilities and authority comes directly from laws passed by Congress. Others come from Executive Orders issued by the President. The radiological emergency response roles assigned to the Agency under various plans are based on EPA's existing authorities.

Field teams (teams that go to the scene of the emergency) will deploy as quickly as possible after notification. Shortly after arriving at the scene, the RERT begins environmental measurement and guidance activities. They begin monitoring, sampling, and laboratory analysis. They also advise state and local authorities on protecting local residents from exposure to harmful radiation levels.

If needed, the RERT can drive its mobile emergency response laboratories and support equipment to any site in the United States within 2 to 4 days.

Members of EPA's **Radiological Emergency Response Team (RERT)**, laboratories, and other specialists in EPA's Headquarters and ten regional offices continually conduct planning and training activities:

- developing plans for responding to different kinds of radiological accidents or emergencies
- training and guiding planning activities for states and local emergency response organizations who are likely to be first on the scene
- testing response plans in exercises that also improve coordination and communication among emergency response organizations.

The EPA's RERT website is located at:

<http://www.epa.gov/radiation/rert/rert.htm>

XV. NUCLEAR/RADIATION RESPONSE AND REGULATORY CONTACTS

DEPARTMENT OF ENERGY (DOE)

www.energy.gov/

tel 202-586-4940

DEPARTMENT OF HEALTH AND HUMAN SERVICES (HHS)

www.hhs.gov ;

tel 202-690-6343.

DEPARTMENT OF HOMELAND SECURITY (DHS)

www.dhs.gov ;

tel 202-282-8010.

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT (HUD)

<http://www.hud.gov/>

tel 202-708-1112

DEPARTMENT OF THE INTERIOR (DOI)

<http://www.doi.gov/>

tel 202-208-3100

DEPARTMENT OF JUSTICE (DOJ)

www.usdoj.gov ;

tel 202-514-2007.

DEPARTMENT OF STATE (DOS)

<http://www.state.gov/>

tel 202-647-4000

DEPARTMENT OF TRANSPORTATION (DOT)

<http://www.dot.gov/>

tel 866-377-8642

DEPARTMENT OF VETERANS AFFAIRS (VA)

<http://www.va.gov/>

tel 800-827-1000

ENVIRONMENTAL PROTECTION AGENCY (EPA)

www.epa.gov

tel 202-564-9828.

FEDERAL BUREAU OF INVESTIGATION (FBI)

www.fbi.gov ;

tel 202-324-3691.

FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA)

www.fema.gov ;

tel 202-646-4600.

GENERAL SERVICES ADMINISTRATION (GSA)

<http://www.gsa.gov/Portal/gsa/ep/home.do?tabId=0>

tel 800-488-3111

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

<http://www.nasa.gov/>

tel 202-358-0001

NATIONAL COMMUNICATIONS SYSTEM (NCS)

<http://www.ncs.gov/>

tel 703-235-5516

703-607-4950 (after 5 p.m., plus weekends and holidays)

NUCLEAR REGULATORY COMMISSION (NRC)

www.nrc.gov ;

tel 301-415-8200

NATIONAL NUCLEAR SECURITY ADMINISTRATION (NNSA)

www.nnsa.doe.gov/ ;

tel 202-586-7371.

TRANSPORTATION SECURITY ADMINISTRATION (TSA)

www.tsa.gov/public/ ;

tel 571-227-2829.

XVI. RADIOLOGICAL ACRONYMS, AND DEFINITIONS

LIST OF ACRONYMS^{68, 69, 70, 71}

AFRRI	Armed Forces Radiobiology Research Institute
CBC	Complete Blood Count
COBRA	Consolidated Omnibus Budget Reconciliation Act
EMTALA	Emergency Medical Treatment and Labor Act
FEMA	Federal Emergency Management Agency
FRMAC	Federal Radiological Monitoring and Assessment Center
FRPCC	Federal Radiological Preparedness Coordinating Committee
HEICS	Hospital Emergency Incident Command Structure
HIPPA	Health Insurance Portability and Accountability Act
IAEA	International Atomic Energy Agency
ICC	Incident Command Center
NCRP	National Council on Radiation Protection and Measurements
NRC	Nuclear Regulatory Commission
REAC/TS	Radiation Emergency Assistance Center/Training Site

GLOSSARY OF RADIOLOGICAL TERMS^{68, 69, 70, 71}

Absolute risk	the proportion of a population expected to get a disease over a specified time period. <i>See also</i> risk, relative risk.
Absorbed dose	the amount of energy deposited by ionizing radiation in a unit mass of tissue. It is expressed in units of joule per kilogram (J/kg), and called “gray” (Gy).
Activity (radioactivity)	the rate of decay of radioactive material expressed as the number of atoms breaking down per second measured in units called becquerels or curies.
Acute exposure	an exposure to radiation that occurred in a matter of minutes rather than in longer, continuing exposure over a period of time. <i>See also</i> chronic exposure, exposure, fractionated exposure.
Acute Radiation Syndrome (ARS)	a serious illness caused by receiving a dose greater than 50 rads of penetrating radiation to the body in a short time (usually minutes). The earliest symptoms are nausea, fatigue, vomiting, and diarrhea. Hair loss, bleeding, swelling of the mouth and throat, and general loss of energy may follow. If the exposure has been approximately 1,000 rads or more, death may occur within 2 – 4 weeks.

Air burst	a nuclear weapon explosion that is high enough in the air to keep the fireball from touching the ground. Because the fireball does not reach the ground and does not pick up any surface material, the radioactivity in the fallout from an air burst is relatively insignificant compared with a surface burst..
Alpha particle	the nucleus of a helium atom, made up of two neutrons and two protons with a charge of +2. Certain radioactive nuclei emit alpha particles. Alpha particles generally carry more energy than gamma or beta particles, and deposit that energy very quickly while passing through tissue. Alpha particles can be stopped by a thin layer of light material, such as a sheet of paper, and cannot penetrate the outer, dead layer of skin. Therefore, they do not damage living tissue when outside the body. When alpha-emitting atoms are inhaled or swallowed, however, they are especially damaging because they transfer relatively large amounts of ionizing energy to living cells. See <i>also</i> beta particle, gamma ray, neutron, x-ray.
Ambient air	the air that surrounds us. Interim Guidelines for Hospital Response to Mass Casualties from a Radiological Incident
Americium (Am)	a silvery metal; it is a man-made element whose isotopes Am-237 through Am-246 are all radioactive. Am-241 is formed spontaneously by the beta decay of plutonium-241. Trace quantities of americium are widely used in smoke detectors, and as neutron sources in neutron moisture gauges.
Atomic Mass Unit (amu)	<p>Atoms have extremely small masses, far too small to be weighed, so we use the atomic mass scale to express the mass of atoms in atomic mass units (amu). Atomic masses are therefore relative masses where the mass of one atom is compared to another. The relative masses of atoms are compared using the as a basis.</p> <p>The ^{12}C isotope is assigned a mass of exactly 12 atomic mass units (amu) and the atomic mass of any atom is then determined relative to the ^{12}C isotope. Therefore one atomic mass unit is equal to 1/12 the mass of a ^{12}C atom. For your information, $1 \text{ amu} = 1.66056 \times 10^{-24} \text{ g}$, and $1 \text{ g} = 6.02214 \times 10^{23} \text{ amu}$</p>

Atom	the smallest particle of an element that can enter into a chemical reaction.
Atomic number	the total number of protons in the nucleus of an atom.
Atomic mass unit (amu)	1 amu is equal to one twelfth of the mass of a carbon-12 atom.
Atomic mass number	the total number of protons and neutrons in the nucleus of an atom.
Atomic weight	the mass of an atom, expressed in atomic mass units. For example, the atomic number of helium-4 is 2, the atomic mass is 4, and the atomic weight is 4.00026.
Background radiation	ionizing radiation from natural sources, such as terrestrial radiation due to radionuclides in the soil or cosmic radiation originating in outer space.
Becquerel (Bq)	the amount of a radioactive material that will undergo one decay (disintegration) per second. <i>For more information, see "Primer on Radiation Measurement" at the end of this document.</i>
Beta particles	electrons ejected from the nucleus of a decaying atom. Although they can be stopped by a thin sheet of aluminum, beta particles can penetrate the dead skin layer, potentially causing burns. They can pose a serious direct or external radiation threat and can be lethal depending on the amount received. They also pose a serious internal radiation threat if beta-emitting atoms are ingested or inhaled. <i>See also</i> alpha particle, gamma ray, neutron, x-ray.
Bioassay	an assessment of radioactive materials that may be present inside a person's body through analysis of the person's blood, urine, feces, or sweat.
Biological half-life	the time required for one half of the amount of a substance, such as a radionuclide, to be expelled from the body by natural metabolic processes, not counting radioactive decay, once it has been taken in through inhalation, ingestion, or absorption. <i>See also</i> radioactive half-life, effective half-life. Interim
Carcinogen:	a cancer-causing substance.

Chain reaction	a process that initiates its own repetition. In a fission chain reaction, a fissile nucleus absorbs a neutron and fissions (splits) spontaneously, releasing additional neutrons. These, in turn, can be absorbed by other fissile nuclei, releasing still more neutrons. A fission chain reaction is self-sustaining when the number of neutrons released in a given time equals or exceeds the number of neutrons lost by absorption in non-fissile material or by escape from the system.
Chronic exposure	exposure to a substance over a long period of time, possibly resulting in adverse health effects. <i>See also</i> acute exposure, fractionated exposure.
Cobalt (Co)	gray, hard, magnetic, and somewhat malleable metal. Cobalt is relatively rare and generally obtained as a byproduct of other metals, such as copper. Its most common radioisotope, cobalt-60 (Co-60), is used in radiography and medical applications. Cobalt-60 emits beta particles and gamma rays during radioactive decay.
Collective dose	the estimated dose for an area or region multiplied by the estimated population in that area or region.
Committed dose	a dose that accounts for continuing exposures expected to be received over a long period of time (such as 30, 50, or 70 years) from radioactive materials that were deposited inside the body
Concentration:	the ratio of the amount of a specific substance in a given volume or mass of solution to the mass or volume of solvent.
Contamination (radioactive)	the deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or people where it may be external or internal. <i>See also</i> decontamination.
Cosmic radiation	radiation produced in outer space when heavy particles from other galaxies (nuclei of all known natural elements) bombard the earth. <i>See also</i> background radiation, terrestrial radiation.

Criticality	a fission process where the neutron production rate equals the neutron loss rate to absorption or leakage. A nuclear reactor is "critical" when it is operating.
Critical mass	the minimum amount of fissile material that can achieve a self-sustaining nuclear chain reaction.
Cumulative dose	the total dose resulting from repeated or continuous exposures of the same portion of the body, or of the whole body, to ionizing radiation.
Curie (Ci)	the traditional measure of radioactivity based on the observed decay rate of 1 gram of radium. One curie of radioactive material will have 37 billion disintegrations in 1 second.
Cutaneous Radiation Syndrome (CRS)	the complex syndrome resulting from radiation exposure of more than 200 rads to the skin. The immediate effects can be reddening and swelling of the exposed area (like a severe burn), blisters, ulcers on the skin, hair loss, and severe pain. Very large doses can result in permanent hair loss, scarring, altered skin color, deterioration of the affected body part, and death of the affected tissue (requiring surgery)..
Decay chain (decay series)	the series of decays that certain radioisotopes go through before reaching a stable form. For example, the decay chain that begins with Interim Guidelines for Hospital Response to Mass Casualties from a Radiological Incident uranium-238 (U-238) ends in lead-206 (Pb-206), after forming isotopes, such as uranium-234 (U-234), thorium-230 (Th-230), radium-226 (Ra-226), and radon-222 (Rn-222).
Decay constant	the fraction of a number of atoms of a radioactive nuclide that disintegrates in a unit of time. The decay constant is inversely proportional to the radioactive half-life.
Decay products (daughter products)	the isotopes or elements formed and the particles and high-energy electromagnetic radiation emitted by the nuclei of radionuclides during radioactive decay. Also known as "decay chain products" or "progeny" (the isotopes and elements). A decay product may be either radioactive or stable.

Decay, radioactive	disintegration of the nucleus of an unstable atom by the release of radiation.
Decontamination	the reduction or removal of radioactive contamination from a structure, object, or person.
Depleted uranium	uranium containing less than 0.7% uranium-235, the amount found in natural uranium. <i>See also</i> enriched uranium.
Deposition density	the activity of a radionuclide per unit area of ground. Reported as becquerels per square meter or curies per square meter.
Deterministic effects	effects that can be related directly to the radiation dose received. The severity increases as the dose increases. A deterministic effect typically has a threshold below which the effect will not occur. <i>See also</i> stochastic effect, nonstochastic effect.
Deuterium	a non-radioactive isotope of the hydrogen atom that contains a neutron in its nucleus in addition to the one proton normally seen in hydrogen. A deuterium atom is twice as heavy as normal hydrogen. <i>See also</i> tritium.
Dirty bomb	a device designed to spread radioactive material by conventional explosives when the bomb explodes. A dirty bomb kills or injures people through the initial blast of the conventional explosive and spreads radioactive contamination over possibly a large area—hence the term “dirty.” Such bombs could be miniature devices or large truck bombs. A dirty bomb is much simpler to make than a true nuclear weapon. <i>See also</i> radiological dispersal device.
Dose (radiation)	radiation absorbed by person’s body. Several different terms describe radiation dose.
Dose coefficient	the factor used to convert radionuclide intake to dose. Usually expressed as dose per unit intake (e.g., sieverts per becquerel).
Dose equivalent	a quantity used in radiation protection to place all radiation on a common scale for calculating tissue

damage. Dose equivalent is the absorbed dose in grays times the quality factor. The quality factor accounts for differences in radiation effects caused by different types of ionizing radiation. Some radiation, including alpha particles, causes a greater amount of damage per unit of absorbed dose than other radiation. The sievert (Sv) is the unit used to measure dose equivalent.

Dose rate	the radiation dose delivered per unit of time.
Dose reconstruction	a scientific study that estimates doses to people from releases of radioactivity or other pollutants. The dose is reconstructed by determining the amount of material released, the way people came in contact with it, and the amount they absorbed.
Dosimeter	a small portable instrument (such as a film badge, thermoluminescent dosimeter [TLD], or pocket dosimeter) for measuring and recording the total accumulated dose of ionizing radiation a person receives.
Dosimetry	assessment (by measurement or calculation) of radiation dose.
Effective dose	a dosimetric quantity useful for comparing the overall health affects of irradiation of the whole body. It takes into account the absorbed doses received by various organs and tissues and weighs them according to present knowledge of the sensitivity of each organ to radiation. It also accounts for the type of radiation and the potential for each type to inflict biologic damage. The effective dose is used, for example, to compare the overall health detriments of different radionuclides in a given mix. The unit of effective dose is the sievert (Sv); $1 \text{ Sv} = 1 \text{ J/kg}$.
Effective half-life	the time required for the amount of a radionuclide deposited in a living organism to be diminished by 50% as a result of the combined action of radioactive decay and biologic elimination. See <i>also</i> biological half-life, decay constant, radioactive half-life.
Electron	an elementary particle with a negative electrical charge and a mass $1/1837$ that of the proton.

Electrons surround the nucleus of an atom because of the attraction between their negative charge and the positive charge of the nucleus. A stable atom will have as many electrons as it has protons. The number of electrons that orbit an atom determine its chemical properties. See *also* neutron.

Electron volt (eV)

a unit of energy equivalent to the amount of energy gained by an electron when it passes from a point of low potential to a point one volt higher in potential.

Element

1) all isotopes of an atom that contain the same number of protons. For example, the element uranium has 92 protons, and the different isotopes of this element may contain 134 to 148 neutrons.

2) In a reactor, a fuel element is a metal rod containing the fissile material.

Enriched uranium

uranium in which the proportion of the isotope uranium-235 has been increased by removing uranium-238 mechanically. See *also* depleted uranium.

Epidemiology

the study of the distribution and determinants of health-related states or events in specified populations; and the application of this study to the control of health problems.

Exposure (radiation)

a measure of ionization in air caused by x-rays or gamma rays only. The unit of exposure most often used is the roentgen. See *also* contamination.

Exposure pathway

a route by which a radionuclide or other toxic material can enter the body. The main exposure routes are inhalation, ingestion, absorption through the skin, and entry through a cut or wound in the skin.

Exposure rate

a measure of the ionization produced in air by x-rays or gamma rays per unit of time (frequently expressed in roentgens per hour).

External exposure

exposure to radiation outside of the body.

Fallout, nuclear

minute particles of radioactive debris that descend slowly from the atmosphere after a nuclear explosion.

Fissile material	any material in which neutrons can cause a fission reaction. The three primary fissile materials are uranium-233, uranium-235, and plutonium-239.
Fission (fissioning)	the splitting of a nucleus into at least two other nuclei that releases a large amount of energy. Two or three neutrons are usually released during this transformation. <i>See also</i> fusion.
Fractionated exposure	exposure to radiation that occurs in several small acute exposures, rather than continuously as in a chronic exposure.
Fusion	a reaction in which at least one heavier, more stable nucleus is produced from two lighter, less stable nuclei. Reactions of this type are responsible for the release of energy in stars or in thermonuclear weapons.
Gamma rays	high-energy electromagnetic radiation emitted by certain radionuclides when their nuclei transition from a higher to a lower energy state. These rays have high energy and a short wave length. All gamma rays emitted from a given isotope have the same energy, a characteristic that enables scientists to identify which gamma emitters are present in a sample. Gamma rays penetrate tissue farther than do beta or alpha particles, but leave a lower concentration of ions in their path to potentially cause cell damage. Gamma rays are very similar to x-rays. <i>See also</i> neutron.
Geiger counter	a radiation detection and measuring instrument consisting of a gasfilled tube containing electrodes, between which an electrical voltage but no current flows. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of the radiation field. Geiger counters are the most commonly used portable radiation detection instruments.
Genetic effects	hereditary effects (mutations) that can be passed on through reproduction because of changes in sperm or ova. <i>See also</i> teratogenic effects, somatic effects.

Gray (Gy)	a unit of measurement for absorbed dose. It measures the amount of energy absorbed in a material. The unit Gy can be used for any type of radiation, but it does not describe the biological effects of the different radiations.
Half-life	the time any substance takes to decay by half of its original amount. <i>See also</i> biological half-life, decay constant, effective half-life, radioactive half-life.
High-level radioactive waste	the radioactive material resulting from spent nuclear fuel reprocessing. This can include liquid waste directly produced in reprocessing or any solid material derived from the liquid wastes having a sufficient concentration of fission products. Other radioactive materials can be designated as high-level waste, if they require permanent isolation. This determination is made by the U.S. Nuclear Regulatory Commission on the basis of criteria established in U.S. law. <i>See also</i> lowlevel waste, transuranic waste.
Hot spot	any place where the level of radioactive contamination is considerably greater than the area around it.
Ingestion	1) the act of swallowing; 2) in the case of radionuclides or chemicals, swallowing radionuclides or chemicals by eating or drinking.
Inhalation	1) the act of breathing in; 2) in the case of radionuclides or chemicals, breathing in radionuclides or chemicals.
Internal exposure	exposure to radioactive material taken into the body.
Iodine	a nonmetallic solid element. There are both radioactive and non-radioactive isotopes of iodine. Radioactive isotopes of iodine are widely used in medical applications. Radioactive iodine is a fission product and is the largest contributor to people's radiation dose after an accident at a nuclear reactor.
Ion	an atom that has fewer or more electrons than it has protons causing it to have an electrical charge and, therefore, be chemically reactive.

Ionization	the process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiation can cause ionization.
Ionizing radiation	any radiation capable of displacing electrons from atoms, thereby producing ions. High doses of ionizing radiation may produce severe skin or tissue damage. <i>See also</i> alpha particle, beta particle, gamma ray, neutron, x-ray.
Irradiation	exposure to radiation.
Isotope	a nuclide of an element having the same number of protons but a different number of neutrons.
Kiloton (Kt)	the energy of an explosion that is equivalent to an explosion of 1,000 tons of TNT. One kiloton equals 1 trillion (10 ¹²) calories. <i>See also</i> megaton.
Latent period	the time between exposure to a toxic material and the appearance of a resultant health effect.
Lead (Pb)	a heavy metal. Several isotopes of lead, such as Pb-210 which emits beta radiation, are in the uranium decay chain.
Local radiation injury (LRI)	acute radiation exposure (more than 1,000 rads) to a small, localized part of the body. Most local radiation injuries do not cause death. However, if the exposure is from penetrating radiation (neutrons, x-rays, or gamma rays), internal organs may be damaged and some symptoms of acute radiation syndrome (ARS), including death, may occur. Local radiation injury invariably involves skin damage, and a skin graft or other surgery may be required.
Low-level waste (LLW)	radioactively contaminated industrial or research waste such as paper, rags, plastic bags, medical waste, and water-treatment residues. It is waste that does not meet the criteria for any of three other categories of radioactive waste: spent nuclear fuel and high-level radioactive waste; transuranic radioactive waste; or uranium mill tailings. Its

categorization does not depend on the level of radioactivity it contains.

Megaton (Mt)

the energy of an explosion that is equivalent to an explosion of 1 million tons of TNT. One megaton is equal to a quintillion (10¹⁸) calories. *See also* kiloton.

Molecule

a combination of two or more atoms that are chemically bonded. A molecule is the smallest unit of a compound that can exist by itself and retain all of its chemical properties.

Neoplastic

pertaining to the pathologic process resulting in the formation and growth of an abnormal mass of tissue.

Neutron

a small atomic particle possessing no electrical charge typically found within an atom's nucleus. Neutrons are, as the name implies, neutral in their charge. That is, they have neither a positive nor a negative charge. A neutron has about the same mass as a proton. *See also* alpha particle, beta particle, gamma ray, nucleon, xray.

Non-ionizing radiation

radiation that has lower energy levels and longer wavelengths than ionizing radiation. It is not strong enough to affect the structure of atoms it contacts but is strong enough to heat tissue and can cause harmful biological effects. Examples include radio waves, microwaves, visible light, and infrared from a heat lamp.

Non-stochastic effects

effects that can be related directly to the radiation dose received. The effect is more severe with a higher dose. It typically has a threshold, below which the effect will not occur. These are sometimes called deterministic effects. For example, a skin burn from radiation is a non-stochastic effect that worsens as the radiation dose increases. *See also* stochastic effects.

Nuclear energy

the heat energy produced by the process of nuclear fission within a nuclear reactor or by radioactive decay.

Nuclear fuel cycle

the steps involved in supplying fuel for nuclear power plants. It can include mining, milling, isotopic enrichment, fabrication of fuel elements, use in reactors, chemical reprocessing to recover the fissile

material remaining in the spent fuel, reenrichment of the fuel material refabrication into new fuel elements, and waste disposal.

Nuclear tracers	radioisotopes that give doctors the ability to "look" inside the body and observe soft tissues and organs, in a manner similar to the way x-rays provide images of bones. A radioactive tracer is chemically attached to a compound that will concentrate naturally in an organ or tissue so that an image can be taken.
Nucleon	a proton or a neutron; a constituent of the nucleus of an atom.
Nucleus	the central part of an atom that contains protons and neutrons. The nucleus is the heaviest part of the atom.
Nuclide	a general term applicable to all atomic forms of an element. Nuclides are characterized by the number of protons and neutrons in the nucleus, as well as by the amount of energy contained within the atom.
Pathways	the routes by which people are exposed to radiation or other contaminants. The three basic pathways are inhalation, ingestion, and direct external exposure. See <i>also</i> exposure pathway.
Penetrating radiation	radiation that can penetrate the skin and reach internal organs and tissues. Photons (gamma rays and x-rays), neutrons, and protons are penetrating radiations. However, alpha particles and all but extremely high-energy beta particles are not considered penetrating radiation.
Photon	discrete "packet" of pure electromagnetic energy. Photons have no mass and travel at the speed of light. The term "photon" was developed to describe energy when it acts like a particle (causing interactions at the molecular or atomic level), rather than a wave. Gamma rays and x-rays are photons.
Pitchblende	a brown to black mineral that has a distinctive luster. It consists mainly of urananite (UO ₂), but also contains radium (Ra). It is the main source of uranium (U) ore.

Plume	the material spreading from a particular source and traveling through environmental media, such as air or ground water. For example, a plume could describe the dispersal of particles, gases, vapors, and aerosols in the atmosphere, or the movement of contamination through an aquifer (For example, dilution, mixing, or adsorption onto soil).
Plutonium (Pu)	a heavy, man-made, radioactive metallic element. The most important isotope is Pu-239, which has a half-life of 24,000 years. Pu-239 can be used in reactor fuel and is the primary isotope in weapons. One kilogram is equivalent to about 22 million kilowatt-hours of heat energy. The complete detonation of a kilogram of plutonium produces an explosion equal to about 20,000 tons of chemical explosive. All isotopes of plutonium are readily absorbed by the bones and can be lethal depending on the dose and exposure time.
Polonium (Po)	a radioactive chemical element and a product of radium (Ra) decay. Polonium is found in uranium (U) ores.
Prenatal radiation exposure	radiation exposure to an embryo or fetus while it is still in its mother's womb. At certain stages of the pregnancy, the fetus is particularly sensitive to radiation and the health consequences could be severe above 5 rads, especially to brain function.
Protective Action Guide (PAG)	a guide that tells state and local authorities at what projected dose they should take action to protect people from exposure to unplanned releases of radioactive material into the environment.
Proton:	a small atomic particle, typically found within an atom's nucleus, that possesses a positive electrical charge. Even though protons and neutrons are about 2,000 times heavier than electrons, they are tiny. The number of protons is unique for each chemical element. See <i>also</i> nucleon.
Quality factor (Q)	the factor by which the absorbed dose (rad or gray) is multiplied to obtain a quantity that expresses, on a common scale for all ionizing radiation, the biological

damage (rem) to an exposed person. It is used because some types of radiation, such as alpha particles, are more biologically damaging internally than other types.

Rad (radiation absorbed dose)

a basic unit of absorbed radiation dose. It is a measure of the amount of energy absorbed by the body. The rad is the traditional unit of absorbed dose. It is being replaced by the unit gray (Gy), which is equivalent to 100 rad. One rad equals the dose delivered to an object of 100 ergs of energy per gram of material.

Radiation

energy moving in the form of particles or waves. Familiar radiations are heat, light, radio waves, and microwaves. Ionizing radiation is a very high-energy form of electromagnetic radiation.

Radioactive contamination

the deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or people. It can be airborne, external, or internal. *See also* contamination, decontamination.

Radioactive decay

the spontaneous disintegration of the nucleus of an atom.

Radioactive half-life

the time required for a quantity of a radioisotope to decay by half. For example, because the half-life of iodine-131 (I-131) is 8 days, a sample of I-131 that has 10 mCi of activity on January 1, will have 5 mCi of activity 8 days later, on January 9. *See also:* biological half-life, decay constant, effective half-life.

Radioactive material

material that contains unstable (radioactive) atoms that give off radiation as they decay.

Radioactivity

the process of spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles often accompanied by gamma rays. This process is referred to as decay or disintegration of an atom.

Radioassay

a test to determine the amounts of radioactive materials through the detection of ionizing radiation. Radioassays will detect transuranic nuclides,

uranium, fission and activation products, naturally occurring radioactive material, and medical isotopes.

Radiogenic

health effects caused by exposure to ionizing radiation.

Radiography

1) *medical*: the use of radiant energy (such as x-rays and gamma rays) to image body systems.
 2) *industrial*: the use of radioactive sources to photograph internal structures, such as turbine blades in jet engines. A sealed radiation source, usually iridium-192 (Ir-192) or cobalt-60 (Co-60), beams gamma rays at the object to be checked. Gamma rays passing through flaws in the metal or incomplete welds strike special photographic film (radiographic film) on the opposite side.

**Radioisotope
(radioactive isotope)**

isotopes of an element that have an unstable nucleus. Radioactive isotopes are commonly used in science, industry, and medicine. The nucleus eventually reaches a stable number of protons and neutrons through one or more radioactive decays. Approximately 3,700 natural and artificial radioisotopes have been identified.

**Radiological
or radiologic**

related to radioactive materials or radiation. The radiological sciences focus on the measurement and effects of radiation.

**Radiological dispersal
device (RDD)**

a device that disperses radioactive material by conventional explosive or other mechanical means, such as a spray. *See also* dirty bomb.

**Radionuclide
nuclide.**

an unstable and therefore radioactive form of a

Radium (Ra)

a naturally occurring radioactive metal. Radium is a radionuclide formed by the decay of uranium (U) and thorium (Th) in the environment. It occurs at low levels in virtually all rock, soil, water, plants, and animals. Radon (Rn) is a decay product of radium.

Radon (Rn)

a naturally occurring radioactive gas found in soils, rock, and water throughout the United States. Radon causes lung cancer and is a threat to health because it tends to collect in homes, sometimes to very high

concentrations. As a result, radon is the largest source of exposure to people from naturally occurring radiation.

Relative risk

the ratio between the risk for disease in an irradiated population to the risk in an unexposed population. A relative risk of 1.1 indicates a 10% increase in cancer from radiation, compared with the "normal" incidence. *See also* risk, absolute risk.

Rem (roentgen equivalent, man)

a unit of equivalent dose. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Rem relates the absorbed dose in human tissue to the effective biological damage of the radiation. It is determined by multiplying the number of rads by the quality factor, a number reflecting the potential damage caused by the particular type of radiation. The rem is the traditional unit of equivalent dose, but it is being replaced by the sievert (Sv), which is equal to 100 rem.

Risk

the probability of injury, disease, or death under specific circumstances and time periods. Risk can be expressed as a value that ranges from 0% (no injury or harm will occur) to 100% (harm or injury will definitely occur). Risk can be influenced by several factors: personal behavior or lifestyle, environmental exposure to other material, or inborn or inherited characteristic known from scientific evidence to be associated with a health effect. Because many risk factors are not exactly measurable, risk estimates are uncertain. *See also* absolute risk, relative risk.

Risk assessment

an evaluation of the risk to human health or the environment by hazards. Risk assessments can look at either existing hazards or potential hazards.

Roentgen (R)

a unit of exposure to x-rays or gamma rays. One roentgen is the amount of gamma or x-rays needed to produce ions carrying 1 electrostatic unit of electrical charge in 1 cubic centimeter of dry air under standard conditions.

Sensitivity	ability of an analytical method to detect small concentrations of radioactive material.
Shielding	the material between a radiation source and a potentially exposed person that reduces exposure.
Sievert (Sv)	a unit used to derive a quantity called dose equivalent. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Dose equivalent is often expressed as millionths of a sievert, or micro-sieverts (μSv). One sievert is equivalent to 100 rem.
S.I. units	the Systeme Internationale (or International System) of units and measurements. This system of units officially came into being in October 1960 and has been adopted by nearly all countries, although the amount of actual usage varies considerably.
Somatic effects	effects of radiation that are limited to the exposed person, as distinguished from genetic effects, which may also affect subsequent generations. <i>See also</i> teratogenic effects.
Stable nucleus	the nucleus of an atom in which the forces among its particles are balanced. <i>See also</i> unstable nucleus.
Stochastic effect	effect that occurs on a random basis independent of the size of dose. The effect typically has no threshold and is based on probabilities, with the chances of seeing the effect increasing with dose. If it occurs, the severity of a stochastic effect is independent of the dose received. Cancer is a stochastic effect. <i>See also</i> non-stochastic effect, deterministic effect.
Strontium (Sr)	a silvery, soft metal that rapidly turns yellow in air. Sr-90 is one of the radioactive fission materials created within a nuclear reactor during its operation. Strontium-90 emits beta particles during radioactive decay.
Surface burst	a nuclear weapon explosion that is close enough to the ground for the radius of the fireball to vaporize

surface material. Fallout from a surface burst contains very high levels of radioactivity. *See also* air burst.

Tailings

waste rock from mining operations that contains concentrations of mineral ore that are too low to make typical extraction methods economical.

Thermonuclear device

a “hydrogen bomb.” A device with explosive energy that comes from fusion of small nuclei, as well as fission.

Teratogenic effect

birth defects that are not passed on to future generations, caused by exposure to a toxin as a fetus. *See also* genetic effects, somatic effects.

Terrestrial radiation

radiation emitted by naturally occurring radioactive materials, such as uranium (U), thorium (Th), and radon (Rn) in the earth.

Thorium (Th)

a naturally occurring radioactive metal found in small amounts in soil, rocks, water, plants, and animals. The most common isotopes of thorium are thorium-232 (Th-232), thorium-230 (Th-230), and thorium-238 (Th-238).

Transuranic

pertaining to elements with atomic numbers higher than uranium (92). For example, plutonium (Pu) and americium (Am) are transuranics.

Tritium

(chemical symbol H-3) a radioactive isotope of the element hydrogen (chemical symbol H). *See also* deuterium.

Unstable nucleus

a nucleus that contains an uneven number of protons and neutrons and seeks to reach equilibrium between them through radioactive decay (i.e., the nucleus of a radioactive atom). *See also* stable nucleus.

Uranium (U)

a naturally occurring radioactive element whose principal isotopes are uranium-238 (U-238) and uranium-235 (U-235). Natural uranium is a hard, silverywhite, shiny metallic ore that contains a minute amount of uranium-234 (U-234).

Uranium mill tailings

naturally radioactive residue from the processing of uranium ore. Although the milling process recovers

about 95% of the uranium, the residues, or tailings, contain several isotopes of naturally occurring radioactive material, including uranium (U), thorium (Th), radium (Ra), polonium (Po), and radon (Rn).

Whole body count

the measure and analysis of the radiation being emitted from a person's entire body, detected by a counter external to the body.

Whole body exposure

an exposure of the body to radiation, in which the entire body, rather than an isolated part, is irradiated by an external source.

X-ray

electromagnetic radiation caused by deflection of electrons from their original paths, or inner orbital electrons that change their orbital levels around the atomic nucleus. X-rays, like gamma rays can travel long distances through air and most other materials. Like gamma rays, x-rays require more shielding to reduce their intensity than do beta or alpha particles. X-rays and gamma rays differ primarily in their origin: x-rays originate in the electronic shell; gamma rays originate in the nucleus. *See also* neutron.

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