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# RADIATION

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## POISINDEX® Managements

# RADIATION

**0.0 OVERVIEW**

LIFE SUPPORT

CLINICAL EFFECTS

LABORATORY/MONITORING

TREATMENT OVERVIEW

RANGE OF TOXICITY

**0.1 LIFE SUPPORT**

**A)** This overview assumes that basic life support measures have been instituted.

**0.2 CLINICAL EFFECTS**

**0.2.1** SUMMARY OF EXPOSURE

**A)** The two immediate concerns in radioactive contamination are (1) treatment of life-threatening injuries and (2) decontamination procedures. Initial care should focus on managing the airway and ensuring adequate ventilation and hemodynamic stability. The two most radiosensitive organ systems in the body are the hematopoietic and the gastrointestinal systems.

**B)** ACUTE **RADIATION** SYNDROME - This is a symptom complex following whole body irradiation (> 1 gray (Gy)). It varies in nature and severity, depending upon: (a) dose measured in gray (Gy) (**radiation** absorbed dose, 1 Gy = 1 joule per kilogram of absorbed energy of any type of **radiation** in any tissue), (b) dose rate, (c) dose distribution, and (d) individual susceptibility. Whole-body **radiation** doses can be divided into potentially lethal (2 to 10 Gy), sublethal (less than 2 Gy), and supralethal (greater than 10 Gy) doses. Acute **radiation** syndrome has four clinical phases: prodrome, latent, manifest illness, and recovery. An older unit for **radiation** absorbed dose is the "rad", where 1 rad = 100 ergs of energy absorbed per gram of irradiated tissue. 1 Gy = 100 rads.

**C)** PRODROME - This is an initial toxic period beginning minutes to hours after exposure; its onset and severity are dose-dependent. Minimum dose is unknown, but the prodrome may occur with doses as low as 1 Gy and always with exposure to greater than 4 Gy. At doses less than 4 Gy, the symptoms begin within 24 to 48 hours; at doses greater than 6 Gy, symptoms begin within two hours.

**1)** PRODROMAL phase occurs in the first 48 to 72 hours and is characterized by nausea, vomiting, diarrhea, intestinal cramps, salivation, and dehydration. Fatigue, weakness, apathy, fever, and hypotension are the result of neurovascular dysfunction. At doses below about 5 Gy it lasts 2 to 4 days.

**D)** LATENT period follows the prodromal phase and lasts for approximately 1 to 2 and 1/2 weeks. During this time critical cell populations (leukocytes, platelets) are decreasing as a result of bone marrow insult. The time interval decreases as the dose increases. It is generally a dose-dependent phase of well being.

**1)** The latent phase is longest preceding bone marrow depression of the hematopoietic syndrome (varies between 2 and 6 weeks). Prior to the gastrointestinal syndrome, the latent period lasts from a few days to a week. Preceding the neurovascular syndrome, the latent period is shortest, lasting only a few hours. These times are exceedingly variable and may be modified by the presence of other disease or injury.

**E)** MANIFEST ILLNESS phase is a period when overt illness develops. This phase presents with the clinical symptoms associated with the major organ system injured (bone marrow, intestinal, neurovascular).

**F)** RECOVERY phase or death - recovery may take weeks or months.

**G)** Within the acute **radiation** syndrome is included: CNS syndrome, hematopoietic syndrome, gastrointestinal syndrome, skin, and trauma injuries.

**H)** TRAUMA, MULTIPLE - The combination of even benign-appearing trauma and **radiation** exposure will produce synergistic effects. Mortality is increased because of bleeding diathesis complications, prolonged wound healing, and increased risk of sepsis.

**0.2.5** CARDIOVASCULAR

**A)** Hypotension may occur following the neurovascular stage or due to hypovolemia.

**0.2.6** RESPIRATORY

**A)** Pulmonary **radiation** injury may result in **radiation** pneumonitis and **radiation** pulmonary fibrosis.

**0.2.7** NEUROLOGIC

**A)** Supralethal **radiation** doses may result in headache, acute brain syndrome, alterations in mental status including coma, and (rarely) seizures within minutes of exposure.

**0.2.8** GASTROINTESTINAL

**A)** Gastrointestinal syndrome (nausea/vomiting) commonly occurs after doses of 9 to 20 Gy and may occur following doses as low as 5 Gy. Initial vomiting is followed by persistent diarrhea, which may be bloody.

**0.2.12** FLUID-ELECTROLYTE

**A)** Fluid and electrolyte losses generally occur during the gastrointestinal syndrome.

**0.2.13** HEMATOLOGIC

**A)** A decrease in neutrophils may reflect the degree of exposure. Leukemia may develop following significant exposures. Pancytopenia may occur and predisposes to infections and sepsis, especially in patients with concomitant traumatic injuries.

**0.2.14** DERMATOLOGIC

**A)** Thermonuclear burns may occur. If erythema is produced by a penetrating **radiation**, serious systemic injury is certain.

**B)** A skin dose greater than 3 Gy results in epilation within 2 weeks. Cutaneous **radiation** syndrome has produced cutaneous ulcers, dermal defects, and cutaneous fibrosis.

**0.2.16** ENDOCRINE

**A)** Hypothyroidism or hyperthyroidism may occur. Both benign and malignant thyroid tumors have been associated with ionizing **radiation** exposure.

**0.2.20** REPRODUCTIVE

**A)** In addition to an increased risk of cancer, exposure to ionizing **radiation** is known to affect human reproduction.

**B)** Prenatal ionizing **radiation** exposure may cause congenital anomalies, mental retardation, and an increased incidence of seizures.

**0.2.21** CARCINOGENICITY

**A)** Ionizing **radiation** has carcinogenic effects in many tissues.

**B)** Acute ionizing **radiation** exposure survivors have increased long-term cancer risks. A dose-response relationship exists between exposure to ionizing **radiation** and the risk for the subsequent development of cancer.

## 0.3 LABORATORY/MONITORING

**A)** Baseline laboratory studies should include a CBC with differential count, platelet count, and electrolyte panel. These studies should be repeated frequently in the first 48 hours postexposure.

**B)** See the MEDICAL SURVEILLANCE/LABORATORY section in the main document for more information.

## 0.4 TREATMENT OVERVIEW

**0.4.2** ORAL/PARENTERAL EXPOSURE

**A)** Treatment is symptomatic and supportive. Prevention and treatment of infection is imperative, using broad-spectrum antibiotics with gram-negative coverage.

**1)** Radioactive materials of military significance include: Americium, cesium, cobalt, depleted uranium, iodine, phosphorus, plutonium, radium, strontium, tritium, and uranium.

**B)** Bone marrow depression should be treated with G-CSF or GM-CSF.

**C)** Replace fluids and electrolytes as needed.

**D)** HYPOTENSION: Infuse 10 to 20 mL/kg isotonic fluid. If hypotension persists, administer dopamine (5 to 20 mcg/kg/min) or norepinephrine (ADULT: begin infusion at 0.5 to 1 mcg/min; CHILD: begin infusion at 0.1 mcg/kg/min); titrate to desired response.

**E)** SEIZURES: Administer a benzodiazepine IV; DIAZEPAM (ADULT: 5 to 10 mg, repeat every 10 to 15 min as needed. CHILD: 0.2 to 0.5 mg/kg, repeat every 5 min as needed) or LORAZEPAM (ADULT: 2 to 4 mg; CHILD: 0.05 to 0.1 mg/kg).

**1)** Consider phenobarbital or propofol if seizures recur after diazepam 30 mg (adults) or 10 mg (children > 5 years).

**2)** Monitor for hypotension, dysrhythmias, respiratory depression, and need for endotracheal intubation. Evaluate for hypoglycemia, electrolyte disturbances, hypoxia.

**0.4.3** INHALATION EXPOSURE

**A)** The history obtained at the scene is of great importance. The exact type of exposure, i.e., internal versus external and partial versus whole body exposure, should be obtained.

**B)** If exposure is internal, both the route of entry (oral, inhalation, contaminated open wounds) and the specific radioactive material(s) should be determined. Monitoring exposed patients for contamination and decontamination procedures should be started. All personnel involved in handling patients should wear disposable protective clothing. The patient should be completely undressed and given a soap and water bath or shower (if the patient's condition permits and if the facility exists).

**C)** Acute inhalation of radionuclides presents some difficult problems. Early bronchopulmonary lavage, in addition to chelating, blocking, and diluting agents, may be used. Chronic low-level inhalation of contaminants is more common, and long-term sequelae have been reported.

**D)** Complete recommendations for treatment of **radiation** exposure by all routes is found in the DERMAL EXPOSURE section.

**0.4.5** DERMAL EXPOSURE

**A)** OVERVIEW

**1)** Decontamination with soap and water should be repeated until dosimetry readings become normal; all waste should be saved in special receptacles.

**2)** Complete recommendations for treatment of **radiation** exposure by all routes is found in the ORAL/PARENTERAL EXPOSURE section.

## 0.5 RANGE OF TOXICITY

**A)** In man, the median lethal dose of **radiation** (LD50/60) is estimated to be 3.5 Gy.

# 1.0 SUBSTANCES INCLUDED/SYNONYMS

THERAPEUTIC/TOXIC CLASS

SPECIFIC SUBSTANCES

AVAILABLE FORMS/SOURCES

## 1.1 THERAPEUTIC/TOXIC CLASS

**A)** Ionizing **radiation** is electromagnetic energy or energetic particles emitted from a source. Ionizing **radiation** is able to strip electrons from atoms causing chemical changes in molecules.

**B)** **Radiation** injuries occur secondary to exposure to ionizing **radiation**, e.g., alpha, beta, gamma (including x-rays), and neutron exposure. The exposure may be due to external irradiation (source at some distance from the body), internal contamination (ingestion or inhalation), or contamination of open wounds with radioactive materials.

**C)** The most common radionuclides in the atmosphere are: radon-222, tritium, iodine-129, strontium-90, cesium-137, and krypton-85 (Diffre, 1990).

**D)** Radioactive materials of military significance include: Americium, cesium, cobalt, depleted uranium, iodine, phosphorus, plutonium, radium, strontium, tritium, and uranium.

**1.2 SPECIFIC SUBSTANCES**

**1)** IONIZING **RADIATION**
**2)** **RADIATION**, IONIZING
**3)** GAMMA RAYS
**4)** BETA PARTICLES
**5)** ALPHA PARTICLES
**6)** POSITRONS
**7)** X-RAYS
**8)** NEUTRONS
**9)** RADIOACTIVE MATERIAL
**10)** RADIOACTIVE MATERIAL, ARTICLES MANUFACTURED from NATURAL OR DEPLETED URANIUM AND NATURAL THORIUM
**11)** RADIOACTIVE MATERIAL, EMPTY PACKAGE-ARTICLES MANUFACTURED from NATURAL OR DEPLETED URANIUM OR THORIUM (NATURAL)
**12)** RADIOACTIVE MATERIAL, EMPTY PACKAGES
**13)** RADIOACTIVE MATERIAL, EXCEPTED PACKAGE-EMPTY PACKAGING
**14)** RADIOACTIVE MATERIAL, EXCEPTED PACKAGE-LIMITED QUANTITY OF MATERIAL
**15)** RADIOACTIVE MATERIAL, EXCEPTED PACKAGES
**16)** RADIOACTIVE MATERIAL, INSTRUMENTS AND ARTICLES
**17)** RADIOACTIVE MATERIAL, LIMITED QUANTITY, N.O.S.
**18)** RADIOACTIVITY
**19)** RADIOISOTOPES
**20)** RADIONUCLIDES
**21)** URANIUM METAL, PYROPHORIC
**22)** YELLOW CAKE (SLANG FOR URANIUM OXIDE)

**1.6 AVAILABLE FORMS/SOURCES**

**A)** FORMS

**1)** ALPHA ionizing **radiation** is:
- **1)** 2 neutrons and 2 protons
- **2)** Highly ionizing
- **3)** Travels several centimeters in air and a few microns in tissue
- **4)** Stopped by a thin paper or clothing
- **5)** Threat is inhalation or absorption of alpha emitter in wounds.

**2)** BETA ionizing **radiation** is:
- **1)** High energy "electron" emitted from nucleus
- **2)** Can have wide range of energies depending upon particular radionuclide
- **3)** Moderately penetrating
- **4)**
  - **a)** Up to a few meters in air
  - **b)** Millimeters in tissue
- **5)** Some protection by PPE

**3)** GAMMA or X-Ray photons are:
- **1)** High energy rays
- **2)** Very penetrating
- **3)** Difficult to shield (need lead or other dense material)
- **4)** PPE will not protect against photon **radiation**

**4)** NEUTRONS ionizing **radiation** are:
- **1)** Neutral particles emitted from the nucleus
- **2)** Can be very penetrating
- **3)** Requires special consideration for shielding

**5)** Units of measure of **radiation** include (1) gray (Gy) - basic unit for measuring **radiation** dose; (2) rem - quantifies the amount of damage that is suspected from a particular type of **radiation** (Jarrett, 1999).

**6)** **Radiation** half-life is the time required for a radioactive substance to lose half of its radioactivity. Each radionuclide has a unique half-life, with half-lives ranging from extremely short (fraction of a second) to millions of years (Jarrett, 1999).

**B)** SOURCES

**1)** **Radiation** exposure may occur in medical, industrial, and laboratory accidents in which individuals are exposed to unacceptably high doses of **radiation** (ICRP, 1977; Gains, 1989; Wagner et al, 1994). With increased use of radioactive materials, there is also an increased need for transport of such materials with the attendant risk of transport accidents and releases. In addition, there remains the possibility of exposure of large masses of people through detonation of nuclear weapons (Conklin et al, 1983).

**2)** Ionizing **radiation**, resulting from decay of unstable nuclei, consists of three classes of ionizing **radiation**: alpha, beta, and gamma **radiation** (NATO , 1995).

**a)** Alpha **radiation** (alpha particles) are helium nuclei which are mainly emitted from heavy nuclei such as uranium-235 or plutonium-239. The range of these particles is a few centimeters in air, and a few tenths of a millimeter in body tissue. These particles generally can not penetrate human skin, but may cause damage when ingested or inhaled.

**b)** Beta **radiation** (beta particles) consists of electrons and positrons which can be stopped by 1 cm of water or 10 m of air. In body tissue beta **radiation** has a range of up to 10 mm. Strontium-90, a beta-emitting substance, can penetrate skin and can also be systemically absorbed through ingestion and inhalation.

**c)** Gamma **radiation** (gamma rays) consists of photons with a large range as compared with alpha and beta **radiation**. A human body

may only partly stop gamma **radiation** and it is only minimally stopped by air. Shielding by lead or other dense material is required to stop gamma **radiation**.

**3)** SOURCES OF LARGE RADIOACTIVE DISCHARGES

**a)** REACTOR ACCIDENTS - Radioactive substances such as I-131 may be released from nuclear power reactors (Becker, 1987) Jarrett. 1999). Nuclear energy production carries the extremely small risk of **radiation** accidents and **radiation** exposure of the general population worldwide (Champlin et al, 1988).

**b)** WINDSCALE (Sellafield, England, 1957): 30,000 Ci of iodine-131, 12,000 Ci of tellurium-132, and 600 Ci of cesium-137 were released (Diffre, 1990). A curie (Ci) is a unit of activity equal to 3.61 x 10(10) disintegration per second.

**c)** KYSCHTYMSK (Urals, 1957): 1 x 10(6) Ci of strontium-90 were estimated to have contaminated an area of 100 to 1,000 square kilometers (Diffre, 1990).

**d)** THREE MILE ISLAND (USA, 1979): Approximately 6 x 10(11) Bq of iodine-131 was released (Diffre, 1990). A becquerel (Bq) is a unit of activity, with 1 Bq equal to 1 disintegration/second. 1 curie equals 3.61 x 10(10) Bq.

**e)** CHERNOBYL (Byelorussia/Ukraine, 1986): 10 x 10(7) Ci of strontium-90 was reported to have been released, causing 2000 to 3000 square kilometers of soil to be unfit for agriculture (Diffre, 1990).

**4)** OTHER SOURCES

**a)** MILK: Iodine-131 is concentrated in the milk of herbivorous animals.

**b)** RADIUM-226: Is absorbed by plants and animals and its concentration in the human body results from ingestion of food (Diffre, 1990).

**c)** RAINWATER: Usually contains beryllium, carbon-14, tritium, strontium-90, and cesium-137; total normal beta radioactivity is around 1 Bq/L (Diffre, 1990).

**d)** UNDERGROUND WATER: Contains uranium-238 and related products and radium-226. It also contains radon-222 which can be highly concentrated at the source of thermal springs (Diffre, 1990).

**e)** SEAWATER: Beta radioactivity, primarily from potassium-40, is around 10 Bq/L (Diffre, 1990).

**f)** BULLETS: Depleted uranium, "DU", used in armor-piercing shells contains 99.75 percent U-238; soldiers handling or shot with these bullets may be exposed (Christensen, 1993).

**g)** Common fission products from nuclear tests that have fallen onto the surface of the globe include: strontium-90, cesium-137, iodine-129, and iodine-131 (Diffre, 1990).

**1)** Strontium-90 has chemical properties similar to calcium and is deposited in bone.

**2)** Cesium-137 behaves similarly to potassium, but it remains in the human body 2 to 5 times longer.

**3)** Iodine-129 has an atmospheric half-life of 16 x 10(6) years. Radioactive iodine is stored by mammals in the thyroid gland; there its concentration is 3 to 4 times that of exposed grass.

**C)** USES

**1)** AMERICIUM-241 is a decay daughter of plutonium and is an alpha emitter, readily detectable with a standard radiac instrument due to emission of a 60-kEv gamma ray. Its use includes smoke detectors and other instruments, and it is found in fallout from a nuclear weapon detonation. It is considered a heavy metal poison, but in large radioactive doses, can cause whole-body irradiation. 75% of an initial lung burden is absorbed with 10% of the particles retained in the lung. GI absorption is minimal, but absorption through skin wounds may be rapid. Elimination occurs via urinary and hepatic excretion (Jarrett, 1999).

**2)** CESIUM-137 may be found in medical radiotherapy devices. It was reported to be used in the Chechen RDD threat against Moscow. Both gamma rays and beta **radiation** are emitted and can be readily detected by gamma instruments. Absorption is complete via the lungs, GI tract and skin wounds. It is soluble in most forms and is treated by metabolism as a potassium analog. Excretion is via the urine. Whole-body irradiation is the primary toxicity, with deaths due to acute **radiation** syndrome reported (Jarrett, 1999).

**3)** COBALT-60 is commonly used in medical radiotherapy devices and commercial food irradiators. Most commonly, contamination is discovered after improper disposal, or after destruction of a hospital or commercial facility. Generation of high-energy gamma rays and 0.31-MeV beta rays are produced. A gamma detector provides easy detection. Uses of cobalt include as a contaminant in an improvised nuclear device to make fallout more radioactive. Rapid absorption occurs from the lungs, but less than 5% will be absorbed via the GI tract. Wound absorption is not known. Whole-body irradiation and acute **radiation** syndrome are its primary toxicities (Jarrett, 1999).

**4)** DEPLETED URANIUM (DU) emits limited alpha, beta, and some gamma **radiation**, but poses no significant **radiation** threat. It is found in armor-piercing munitions, armor, and aircraft counterweights and is readily detectable with a typical end-window G-M (Geiger-Mueller) counter. Inhaled uranium compounds can be metabolized and result in urinary excretion. DU oxides may be inhaled during tank fires or by entering destroyed armored vehicles without a protective mask. Absorption is determined by the chemical state of the uranium, with soluble salts being readily absorbed and the metal not being absorbed. If DU metal fragments become encapsulated in wounds, they are gradually metabolized, resulting in whole-body distribution, especially to bones and kidney. No renal toxicity has been documented to date. DU does cross the placenta (Jarrett, 1999).

**5)** IODINE-131, 132, 134, and 135 are found after reactor accidents and following the destruction of a nuclear reactor by hostile forces. Radioactive iodine (RAI), a normal fission product found in reactor fuel rods, is released by rupturing the reactor core and its containment vessel. Wind patterns at the time of destruction determine the fallout pattern. Most of its **radiation** is beta rays, with some gamma. Toxicity is primarily to the thyroid gland. RAI concentrates in the thyroid due to uptake by this gland, and allows local irradiation similar to therapeutic thyroid ablation. Following the Chernobyl disaster, a high incidence of childhood thyroid carcinoma was reported (Jarrett, 1999).

**6)** PHOSPHORUS-32 is usually found in research laboratories and in medical facilities with use as a tracer. It emits strong beta rays and can be detected with the beta shield open on a beta-gamma detector. It is completely absorbed from all sites and is deposited in the bone marrow and other rapidly replicating cells. Local irradiation results in cell damage (Jarrett, 1999).

**7)** PLUTONIUM-239, -238 is produced from uranium in reactors and is the primary fissionable material in nuclear weapons and is the predominant radioactive contaminant in nuclear weapons accidents. Its primary **radiation** is in the form of alpha particles, thus not presenting an external irradiation hazard. It is ALWAYS contaminated with americium, which is a fairly readily detectable x-ray by use of thin-walled gamma probe. Primary toxicity is via the inhalation route, with 5-micron or smaller particles remaining in the lung and metabolized based on its salt solubility. Local irradiation damage is caused by remaining particles in the lungs. The chemical state of plutonium determines its GI absorption, with the metal not being absorbed. After 24 hours, stool specimens are positive and after 2 weeks urine specimens are positive. Wound absorption is variable. Plutonium is able to be washed from intact skin (Jarrett, 1999).

**8)** RADIUM-226 has no military use, but may be found in FSU equipment as instrument illumination, in industrial applications, and in older medical equipment. Its primary **radiation** is due to alpha particles, but daughter products emit beta and gamma rays, which in quantity may present a serious external irradiation hazard. Exposures are usually by ingestion, with 30% absorption. Wound absorption is not known, but radium will follow calcium to bone deposition. Leukemia, aplastic anemia, and sarcomas are associated with chronic exposures (Jarrett, 1999).

**9)** STRONTIUM-90 is a direct fission product (daughter) of uranium, with it and its daughters emitting both beta and gamma rays which can

be an external irradiation hazard if present in quantity. Strontium follows calcium and is readily absorbed via both respiratory and GI routes. Up to 50% of a **radiation** dose will be deposited in bone (Jarrett, 1999).

**10)** TRITIUM (hydrogen-3) is hydrogen with a nucleus composed of two neutrons and one proton. It has found use in nuclear weapons and in the U.S. (and other Western countries) in luminescent gun sights and muzzle-velocity detectors. It is NOT likely to be a hazard except within a confined space. Tritium gas is rapidly diffused into the atmosphere. Since tritium is a beta emitter, it is NOT a significant irradiation hazard. Water formed from tritium (HTO) is completely absorbed and equilibrates with body water. Excretion is via the urine, with urine samples positive within an hour of significant exposure. A single acute exposure has NOT been reported to result in any significant health effects (Jarrett, 1999).

**11)** URANIUM-238, -235, -239 can be found, in increasing order of radioactivity, in depleted uranium (DU), natural uranium, fuel rods, and weapons-grade material. Alpha, beta, and gamma **radiation** are emitted from uranium and its daughters. Neither DU nor natural uranium present any serious irradiation threats. Significant levels of gamma particles are emitted from used fuel rods and weapons-grade (enriched) uranium containing fission products. Following placement of enough enriched uranium together, a critical mass may form and emit lethal levels of **radiation**. This scenario could occur in a fuel-reprocessing plant or melted reactor core. Following inhalation, uranium compounds may be metabolized and excreted in the urine. Following an acute exposure, uranium urine levels of 100 mcg/dL may cause renal failure. Absorption is determined by the chemical state of the uranium, with soluble salts readily absorbed and the metal not absorbed (Jarrett, 1999).

## 3.0 CLINICAL EFFECTS

SUMMARY OF EXPOSURE

VITAL SIGNS

HEENT

CARDIOVASCULAR

RESPIRATORY

NEUROLOGIC

GASTROINTESTINAL

FLUID-ELECTROLYTE

HEMATOLOGIC

DERMATOLOGIC

MUSCULOSKELETAL

ENDOCRINE

PSYCHIATRIC

REPRODUCTIVE

CARCINOGENICITY

GENOTOXICITY

OTHER

### 3.1 SUMMARY OF EXPOSURE

**A)** The two immediate concerns in radioactive contamination are (1) treatment of life-threatening injuries and (2) decontamination procedures. Initial care should focus on managing the airway and ensuring adequate ventilation and hemodynamic stability. The two most radiosensitive organ systems in the body are the hematopoietic and the gastrointestinal systems.

**B)** ACUTE **RADIATION** SYNDROME - This is a symptom complex following whole body irradiation (> 1 gray (Gy)). It varies in nature and severity, depending upon: (a) dose measured in gray (Gy) (**radiation** absorbed dose, 1 Gy = 1 joule per kilogram of absorbed energy of any type of **radiation** in any tissue), (b) dose rate, (c) dose distribution, and (d) individual susceptibility. Whole-body **radiation** doses can be divided into potentially lethal (2 to 10 Gy), sublethal (less than 2 Gy), and supralethal (greater than 10 Gy) doses. Acute **radiation** syndrome has four clinical phases: prodrome, latent, manifest illness, and recovery. An older unit for **radiation** absorbed dose is the "rad", where 1 rad = 100 ergs of energy absorbed per gram of irradiated tissue. 1 Gy = 100 rads.

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**D)** LATENT period follows the prodromal phase and lasts for approximately 1 to 2 and 1/2 weeks. During this time critical cell populations (leukocytes, platelets) are decreasing as a result of bone marrow insult. The time interval decreases as the dose increases. It is generally a dose-dependent phase of well being.

**1)** The latent phase is longest preceding bone marrow depression of the hematopoietic syndrome (varies between 2 and 6 weeks). Prior to the gastrointestinal syndrome, the latent period lasts from a few days to a week. Preceding the neurovascular syndrome, the latent period is

shortest, lasting only a few hours. These times are exceedingly variable and may be modified by the presence of other disease or injury.

**E)** MANIFEST ILLNESS phase is a period when overt illness develops. This phase presents with the clinical symptoms associated with the major organ system injured (bone marrow, intestinal, neurovascular).

**F)** RECOVERY phase or death - recovery may take weeks or months.

**G)** Within the acute **radiation** syndrome is included: CNS syndrome, hematopoietic syndrome, gastrointestinal syndrome, skin, and trauma injuries.

**H)** TRAUMA, MULTIPLE - The combination of even benign-appearing trauma and **radiation** exposure will produce synergistic effects. Mortality is increased because of bleeding diathesis complications, prolonged wound healing, and increased risk of sepsis.

## 3.3 VITAL SIGNS

### 3.3.5 PULSE

**A)** THERMONUCLEAR WEAPON DETONATION - Vital signs will be those of severely burned or traumatized patients.

**B)** PEACETIME EXPOSURE -

**1)** IMMEDIATE - With few exceptions, no change in vital signs will be noted other than an increase in pulse rate secondary to anxiety.

**2)** DELAYED - Hours to days after exposure, vital signs reflect manifestations of acute **radiation** syndrome, including an increase in heart rate and a decrease in blood pressure reflecting dehydration and blood loss secondary to gastrointestinal syndrome.

## 3.4 HEENT

### 3.4.3 EYES

**A)** BLINDNESS - Sudden exposure to high-intensity visible light and infrared **radiation** from detonation will result in eye injury of the chorioretinal areas. Using binoculars will increase the likelihood of damage. Eye injury is due to both infrared energy and photochemical reactions that occur within the retina with light wavelengths in the range of 400 to 500 micrometers (Jarrett, 1999).

**1)** Retinal burns will occur in persons looking directly at the flash. Night vision apparatus (NVA) does NOT amplify the infrared and damaging wavelengths NOR does it cause retinal injury.

**2)** Flashblindness occurs with peripheral observation of a brilliant flash of intense light energy and is a temporary condition due to depletion of photopigment from the retina. This may last for a few seconds (daytime) up to 30 minutes (night-time).

**B)** CASE SERIES - CATARACTS developed in 8 of 15 patients studied 6 years after being exposed to large amounts of beta **radiation** during the Chernobyl accident (Peter et al, 1994).

**C)** NYSTAGMUS - A continuous rolling movement of the eyeballs has been noted in patients following **radiation** exposure (Natl Acad Sci, 1963).

### 3.4.5 NOSE

**A)** ABNORMAL SENSATIONS - Persons exposed to ionizing **radiation** may complain of abnormal sensations of taste and smell (Natl Acad Sci, 1963).

### 3.4.6 THROAT

**A)** ABNORMAL SENSATIONS - Persons exposed to ionizing **radiation** may complain of abnormal sensations of taste and smell (Natl Acad Sci, 1963).

## 3.5 CARDIOVASCULAR

### 3.5.1 SUMMARY

**A)** Hypotension may occur following the neurovascular stage or due to hypovolemia.

### 3.5.2 CLINICAL EFFECTS

**A)** HYPOTENSIVE EPISODE

**1)** Hypotension may occur during the neurovascular syndrome or as a result of hypovolemia (Jarrett, 1999).

## 3.6 RESPIRATORY

### 3.6.1 SUMMARY

**A)** Pulmonary **radiation** injury may result in **radiation** pneumonitis and **radiation** pulmonary fibrosis.

### 3.6.2 CLINICAL EFFECTS

**A)** PNEUMONITIS

**1)** **Radiation** pneumonitis is a well-recognized syndrome associated with pulmonary **radiation** injury (secondary to **radiation** therapy) (Gibson et al, 1988) and as an effect from exposure to elevated levels of airborne radioactive particles (dust) from reactor halls of nuclear power plants (Salovsky et al, 2000). A latent period between **radiation** exposure and development of acute pulmonary reactions is common. Dyspnea (in 93 percent of patients) and cough (in 58 percent of patients) are the most common symptoms. Routine chest examinations usually reveal normal physical findings. Skin changes due to **radiation** exposure do not correlate well with pulmonary changes. Early onset of symptoms may indicate a more serious clinical course (Movsas et al, 1997).

**B)** FIBROSIS OF LUNG

**1)** **Radiation** pulmonary fibrosis resulting from chronic lung damage is another well-recognized syndrome associated with pulmonary **radiation** injury (secondary to **radiation** therapy). Evolution of permanent fibrotic changes usually occurs over 6 to 24 months, then remains stable after 2 years. Patients may have no previous pneumonitis and may be asymptomatic or have varying degrees of dyspnea. If a large volume of lung is irradiated, chronic pulmonary insufficiency may evolve and may progress to pulmonary hypertension and cor pulmonale (Movsas et al, 1997).

**C)** HISTOPATHOLOGY FINDING

**1)** Histopathologic changes are divided into 3 stages: early (0 to 2 months after **radiation** therapy), intermediate (2 to 9 months after **radiation** therapy), and late (greater than 9 months after **radiation** therapy) (Movsas et al, 1997).

**a)** EARLY STAGE - characterized by small vessel and capillary injury with development of vascular congestion and increased capillary permeability. Criteria developed for diagnosis of early stage include: hyaline membranes, swelling and destruction of alveolar lining cells with hyperplasia and atypia, and edema.

**b)** INTERMEDIATE STAGE - characterized by platelet, fibrin and collagen obstruction of pulmonary capillaries. Septae have interstitial fibrosis with bands of collagen and alveolar-lining cells become hyperplastic. Alveolar walls become infiltrated with

fibroblasts.
**c)** LATE STAGE - a chronic stage occurs after severe **radiation** injury, with a histopathologic appearance of progressive alveolar septal thickening and progressive vascular sclerosis.

**3.7 NEUROLOGIC**

**3.7.1** SUMMARY

**A)** Supralethal **radiation** doses may result in headache, acute brain syndrome, alterations in mental status including coma, and (rarely) seizures within minutes of exposure.

**3.7.2** CLINICAL EFFECTS

**A)** CENTRAL NERVOUS SYSTEM FINDING

**1)** CNS SYNDROME or NEUROVASCULAR SYNDROME within the acute **radiation** syndrome is associated only with very high acute **radiation** doses of 20 to 40 Gy. At lower doses in this syndrome, hypotension may occur. The latent period is very short (several hours to 1 to 3 days). The clinical course consists of a steadily deteriorating state of consciousness with eventual coma and death. Seizures may or may not occur and there may be little or no indication of increased intracranial pressure (Jarrett, 1999). Acute organic brain syndrome and alterations in mental status, including coma, occurring within a few minutes of exposure indicate exposure to a supralethal dose (greater than 12 Gy) (Andrews & Cloutier, 1965).

**2)** Although psychological and behavioral disturbances can be expected to occur from exposure to even relatively low doses, the early development of frank objective neurologic signs such as ataxia, nystagmus, and muscle tremors requires exposure to massive doses. Seizures as a component of the acute **radiation** syndrome in humans are rare.

**3)** After total-body irradiation, the early signs and symptoms of nonfatal central nervous system injury may disappear prior to the appearance of the gastrointestinal syndrome.

**4)** When an individual has been exposed to a nonuniform dose with a relatively high dose to the head, transient central nervous system symptoms may develop but survival is possible provided the dose to hematopoietic tissue and intestines is sufficiently low.

**B)** HEADACHE

**1)** The patient may complain of a severe, diffuse, and unrelenting headache.

**2)** A headache occurring early (within a few minutes of exposure) indicates exposure to a supralethal dose (greater than 12 Gy) (Andrews & Cloutier, 1965).

**C)** DIZZINESS

**1)** Patients may experience vertigo following **radiation** exposure (Natl Acad Sci, 1963).

**D)** ATAXIA

**1)** Ataxia may be noted in patients exposed to high doses of **radiation** (Natl Acad Sci, 1963).

**E)** SEIZURE

**1)** Seizures will occur within a few minutes of exposure to a supralethal dose (greater than 12 Gy) but are rare (Andrews & Cloutier, 1965). Jarrett (1999) reports that very high acute **radiation** doses associated with an early transient syndrome (lower limit of exposure, 20 to 40 Gy) are followed by a deteriorating state of consciousness with vascular instability, and seizures; increased intracranial pressure may or may not occur.

**2)** In the children of pregnant Japanese atomic bomb survivors, the incidence of seizure was highest following irradiation at the 8th through 15th weeks after fertilization (Dunn et al, 1990).

**F)** NEUROLOGICAL DEFICIT

**1)** In a cohort of 888 children whose mothers were exposed to ionizing **radiation** from atom bomb detonations, those who were exposed at 8 to 15 weeks postovulation had significantly worse scores on repetitive action tests. Those exposed at 0 to 7 weeks postovulation had decreased IQ's (Yoshimaru et al, 1995).

**a)** These effects were not seen in children whose mothers were exposed at weeks 16 to 25 postovulation.

**G)** MULTIPLE SCLEROSIS

**1)** A Scandinavian case/referent study of possible occupational and environmental risk factors for development of multiple sclerosis found that the greatest risk was occupational exposure to ionizing **radiation** (Landtblom et al, 1993). This possible association has not been confirmed.

**3.8 GASTROINTESTINAL**

**3.8.1** SUMMARY

**A)** Gastrointestinal syndrome (nausea/vomiting) commonly occurs after doses of 9 to 20 Gy and may occur following doses as low as 5 Gy. Initial vomiting is followed by persistent diarrhea, which may be bloody.

**3.8.2** CLINICAL EFFECTS

**A)** GASTROENTERITIS

**1)** CHARACTERISTICS - The GASTROINTESTINAL SYNDROME resulting from **radiation** exposure causing intestinal damage is regularly seen after doses of 9 to 20 Gy and may be present after doses as low as 6 Gy. It is characterized initially by nausea and vomiting beginning shortly after exposure; the higher the exposed dose, the earlier the onset (Andrews & Cloutier, 1965; Jarrett, 1999). Onset may be within 30 minutes after exposure. Protracted nausea and vomiting also occur. The gastrointestinal syndrome is associated with sepsis and opportunistic infections. At 10 days, bloody diarrhea may develop. In severe cases death results.

**2)** MECHANISM - Because they have a rapid turnover rate, the cells of the GI tract, particularly the small intestinal villi, are affected earliest by exposure to ionizing **radiation**. Shrinkage of villi and morphological changes in mucosal cells occur as new cell production is diminished. Denudation of the intestinal mucosa occurs. Concomitant injury to the microvasculature of the mucosa results in hemorrhage and marked fluid and electrolyte loss leading to shock. These events generally occur within 1 to 2 weeks following irradiation (Jarrett, 1999). Direct **radiation** exposure of the vomiting center in the medulla oblongata will also cause nausea and vomiting.

**3)** CLINICAL SIGNIFICANCE - If nausea and vomiting are absent, it may be assumed the dose was relatively low. The onset of nausea and vomiting within three hours of exposure indicates a significant dose and warrants hospital admission for observation.

**B)** DIARRHEA

**1)** The initial nausea and vomiting are followed by persistent diarrhea, which may be bloody. The presence of high fever and persistent bloody diarrhea secondary to high doses is an ominous sign (Andrews & Cloutier, 1965). Immediate explosive bloody diarrhea indicates a potentially lethal dose (Conklin et al, 1983).

**C)** HEMATEMESIS

**1)** Bloody emesis may occur secondary to exposure to higher doses (Finch, 1987).

**D)** ESOPHAGEAL INJURY

**1)** **RADIATION**-INDUCED ESOPHAGEAL INJURY - Although the esophagus is a relatively **radiation**-tolerant organ, development of acute **radiation** esophagitis during treatment of a number of cancers may be common and chronic **radiation** esophagitis and perhaps **radiation**-induced esophageal cancer may also occur (Vanagunas et al, 1990).

## 3.12 FLUID-ELECTROLYTE

**3.12.1** SUMMARY

**A)** Fluid and electrolyte losses generally occur during the gastrointestinal syndrome.

**3.12.2** CLINICAL EFFECTS

**A)** ELECTROLYTE DEPLETION

**1)** Electrolyte changes are not diagnostic. Any changes will reflect consequences of protracted vomiting and diarrhea, such as hypochloremia or hypokalemia. Marked fluid and electrolyte losses will occur during the gastrointestinal syndrome following **radiation** exposure (Jarrett, 1999).

## 3.13 HEMATOLOGIC

**3.13.1** SUMMARY

**A)** A decrease in neutrophils may reflect the degree of exposure. Leukemia may develop following significant exposures. Pancytopenia may occur and predisposes to infections and sepsis, especially in patients with concomitant traumatic injuries.

**3.13.2** CLINICAL EFFECTS

**A)** MYELOSUPPRESSION

**1)** Depression of bone marrow function leading to pancytopenia occurs following **radiation** doses of 0.7 to 4 Gy. Changes within the peripheral blood profile may occur as early as 24 hours post-irradiation. Lymphocytes will be depressed most rapidly, and other leukocytes and thrombocytes will be depressed less rapidly. Decreased resistance to infection and anemia varies considerably, from as early as 10 days to as late as 6 to 8 weeks following exposure. Erythrocytes are least affected (Jarrett, 1999).

**2)** The nucleated blood cells are among the most radiosensitive of all body cells. Because of different turnover rates, abnormal hematologic findings occur over days to months following exposure. The most radiosensitive of these cells are the rapidly proliferating ones. Stem cells and immature stages are very radiosensitive. The mature circulating neutrophil normally requires 3 to 7 days to form from its stem cells and depletion begins soon (Jarrett, 1999). The maximum decrease in the WBC count occurs in the second to fourth weeks postexposure, during which time the patient is most susceptible to infection (Conklin et al, 1983).

**a)** Due to the rapid turnover in the granulocyte cell renewal system, evidence of **radiation** damage to marrow myelopoiesis occurs in the peripheral blood within 2 to 4 days following whole body irradiation. Recovery of myelopoiesis lags a little behind erythropoiesis and is accompanied by rapid increases in numbers of differentiating and dividing forms in the marrow. Platelets and mature megakaryocytes are relatively radioresistant; however, the stem cells and immature stages are very radiosensitive. Thrombocytopenia occurs by 3 to 4 weeks after a midlethal-range dose (Jarrett, 1999).

**3)** LYMPHOCYTOPENIA - The absolute lymphocyte count is the most valuable early criterion of the extent of **radiation** injury. If the lymphocyte count is greater than 1500/mm(3) at 48 hours postexposure, it is unlikely the patient has received a fatal dose. Counts between 500 to 1200/mm(3) at 48 hours postexposure indicate a possible lethal dose, while a count less than 500/mm(3) at 48 hours postexposure indicates a probable lethal dose (Natl Acad Sci, 1963; Conklin et al, 1983).

**4)** NEUTROPENIA - In general, a decrease in neutrophils will reflect the degree of exposure. With high-level exposure, there is an early (within 24 hours) neutrophilia (Natl Acad Sci, 1963).

**a)** Fifty-two adult patients were reported to have neutropenia in a 2-year period. Fifty of these patients were survivors of the atomic bomb explosion. The neutropenia in these patients was due to natural killer (NK) or NK-like T-cell proliferative disorders. No underlying hematological disorder was reported in any of the patients (Imamura & Kimura, 2000).

**B)** LEUKEMIA

**1)** CASE REPORT - An industrial radiographer, determined to have been overexposed to gamma **radiation** (at least 10 Gy over 14 years), developed myelodysplasia which progressed to acute myeloid leukemia. Exposure was due to iridium-192 sources, ranging from 10 to 25 Ci, in torch type containers. A principal gamma ray emission of 320 keV is reported from iridium-192, and it has a half-life of 74 days (Lloyd et al, 1994).

**a)** Bone marrow examination revealed hypogranular myelopoiesis, pelger-huet forms, and 20 percent blasts. Abundant micro-megakaryocytes were present with megaloblastic erythropoiesis. Postmortem examinations by ESR of tooth and bone specimens provided evidence that the patient had been excessively irradiated (Lloyd et al, 1994).

**C)** SECONDARY INFECTION

**1)** An infection may occur secondary to pancytopenia. The patient becomes most susceptible to infection in the second to third week postexposure when the maximum decrease in the WBC count occurs.

**2)** For patients with multiple injuries who have survived more than five days, infection is the second most common cause of death (Conklin et al, 1983). Gram-negative bacteria or endotoxin is most commonly responsible.

**D)** THROMBOCYTOPENIC DISORDER

**1)** The platelet count is of little value in the first few days postexposure; however, it should be followed to plan supportive therapy over several weeks to two months postexposure (Natl Acad Sci, 1963; Andrews & Cloutier, 1965). Thrombocytopenia generally occurs by 3 to 4 weeks after midlethal-range doses and results from the killing of stem cells and immature megakaryocyte stages, with subsequent maturational depletion of functional megakaryocytes. After sublethal **radiation**, regeneration of thrombocytopoiesis usually lags behind both erythropoiesis and myelopoiesis (Jarrett, 1999).

**E)** RETICULOCYTE COUNT ABNORMAL

**1)** RETICULOCYTOPENIA - The absence of reticulocytes in the first 3 to 5 days postexposure indicates the patient received a high dose (Natl Acad Sci, 1963; Andrews & Cloutier, 1965).

**F)** ANEMIA

**1)** Anemia takes several weeks to develop because of the normal red blood cell life of 120 days. It will manifest about the time the WBC and platelets counts are beginning to return to normal.

**3.14 DERMATOLOGIC**

**3.14.1** SUMMARY

**A)** Thermonuclear burns may occur. If erythema is produced by a penetrating **radiation**, serious systemic injury is certain.

**B)** A skin dose greater than 3 Gy results in epilation within 2 weeks. Cutaneous **radiation** syndrome has produced cutaneous ulcers, dermal defects, and cutaneous fibrosis.

**3.14.2** CLINICAL EFFECTS

**A)** THERMAL BURN

**1)** THERMONUCLEAR DETONATION - Immediate onset of thermal burns of the skin will occur. Thermal **radiation** 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 within the environment (flame burns). Exposed skin absorbs the infrared; light colors will reflect the infrared and dark colored clothing will absorb it and cause burn patterns. Loose, light colored clothing can reduce the effective range, producing partial thickness burns and giving significant protection against thermal flash burns (Jarrett, 1999). Mortality of thermal burns significantly increases with concomitant **radiation** doses as small as 1.5 Gy.

**2)** **RADIATION** EXPOSURE - The onset of skin burns from **radiation** devices or secondary to beta particle contamination is usually delayed for several days. The possibility of beta burns, which produce damage to the basal stratum of the skin, can be minimized by early vigorous decontamination procedures ((Anon, 2000); Andrews & Cloutier, 1965).

**a)** ACUTE **RADIATION** SYNDROME consists of a prodromal stage occurring within minutes to hours after exposure with an erythematous reaction and a burning itch. Chronic **radiation** syndrome (CRS) follows this several weeks later with a manifestation stage of CRS with erythema, subepidermal blisters and ulcerations. Several weeks later in the subacute stage of CRS, additional erythema with ulcerations may appear. After several months to years, a characteristic **radiation** keratosis, fibrosis, and telangiectases occur as part of the chronic stage of CRS (Gottlober et al, 2000).

**b)** CASE REPORTS - A **radiation** accident occurred during a military exercise when 11 soldiers were accidentally exposed to cesium-137 and developed acute **radiation** syndrome. Sharply demarcated red macules in various body areas occurred during the prodromal stage (Gottlober et al, 2000).

**1)** Two weeks later, ulcers, contaminated with bacteria, appeared in the regions of the initial erythema. Ulcers measured up to 10 cm in diameter. In 7 of the 11 patients, ulcers reached down to the muscles. Cutaneous **radiation** fibrosis was diagnosed in 1 patient. Dermal histologic examination revealed dermal necrosis and cellular detritus in all 11 patients.

**3)** The following skin effects occur following acute **radiation** syndrome (Jarrett, 1999; Gottlober et al, 2000):

| GRAYS | SKIN EFFECT |
|---|---|
| 3 | Epilation |
| 6 | Erythema |
| 10 | Dry desquamation |
| >15 | Moist desquamation |
| >50 | Necrosis |

**B)** ERUPTION

**1)** The amount of **radiation** required to produce erythema depends primarily upon the type of **radiation** involved. It is difficult to base estimates of **radiation** dose on the absence or degree of erythema. The presence of erythema is indicative of a high-level exposure (greater than 6 Gy), at least to superficial tissues. If erythema is produced by penetrating **radiation**, serious systemic injury is certain (Natl Acad Sci, 1963).

**C)** ALOPECIA

**1)** Epilation occurs about two weeks after exposure. It indicates a skin dose of greater than 3 Gy involving penetration deep into the dermis (Andrews & Cloutier, 1965).

**D)** DERMATITIS

**1)** Acute **radiation** dermatitis secondary to x- or gamma-ray exposure is most often seen after **radiation** therapy.

**2)** PEMPHIGUS - Pemphigus lesions may develop in patients treated for cancer with ionizing **radiation** (Correia et al, 1998).

**E)** **RADIATION** INJURY

**1)** DELAYED CUTANEOUS **RADIATION** SYNDROME - Partial body exposure to beta- and gamma-**radiation**, as often happens in accidents, can involve up to 50 percent of total body surface area with lesions including telangiectasias, hemangiomas, **radiation** ulcers and keratoses, splinter hemorrhages, hematolymphangiomas, hyperpigmentation, and fibrosis (Peter et al, 1994).

**2)** CASE REPORT - A male industrial radiographer, exposed to iridium-192 sources ranging from 10 to 25 Ci in torch type containers from 1974 to 1983, then exposed to iridium-192 from wind-out remotely operated sources through 1988, initially complained of dermatitis of the right index finger in 1984 (Lloyd et al, 1994). By 1988, the finger was noted to be sclerotic with telangiectasia and ulcerations of the fingernail. The remaining fingernails were abnormal with linear streaks and a ragged free margin. Skin biopsy of the right index finger revealed keratin thickening with parakeratosis and acanthosis with irregular downgrowths of the basal layer.

**a)** Amputation of the finger was necessary. It was estimated that this worker was exposed to a total average whole body dose of at least 10 Gy over several years of gamma **radiation**. Myelodysplasia progressing to acute myeloid leukemia was the eventual cause of death (Lloyd et al, 1994).

**3)** Physicians occupationally exposed to low-dose ionizing **radiation** had morphological and function alterations of the fingernail-fold dermal microcirculation as compared to unexposed controls (Tomei et al, 1996).

**4)** Iridium-192 exposure in industrial radiologists may cause radiodermatitis with epidermal necrosis, erythema, nail plate loss, intense local pain with a burning sensation, ulcerations, keratotic lesions, and in rare cases the need for digit amputation (Conde-Salazar et al, 1986).

**3.15 MUSCULOSKELETAL**

**3.15.2** CLINICAL EFFECTS

**A)** TREMOR

**1)** Muscle tremor occurs following massive **radiation** exposure (Natl Acad Sci, 1963).

**3.16 ENDOCRINE**

**3.16.1** SUMMARY

**A)** Hypothyroidism or hyperthyroidism may occur. Both benign and malignant thyroid tumors have been associated with ionizing **radiation** exposure.

**3.16.2** CLINICAL EFFECTS

**A)** FINDING OF THYROID FUNCTION

**1)** **Radiation** therapy-associated thyrotoxicosis of either the hypothyroid or hyperthyroid type can occur and may involve an organ-specific autoimmune mechanism (Katayama et al, 1986).

**2)** In survivors of the Nagasaki, Japan atomic bomb detonation, there was a significant dose-response relationship between ionizing **radiation** exposure and thyroid diseases including cancer, adenoma, adenomatous goiter, thyroid nodules, and antibody-positive spontaneous hypothyroidism (Nagataki et al, 1994).

**3)** A significant increase in thyroid autoimmunity was found 6 to 8 years after the Chernobyl accident in children (n=495) exposed to radioactive fallout. The autoimmune response was limited to an increased prevalence of circulating thyroid autoantibodies without evidence of significant thyroid dysfunction. No significant changes of serum FT-4, FT-3, or TSH were noted (Pacini et al, 1998).

**4)** Childhood thyroid carcinoma was reported with an increased incidence rate, especially in the youngest children, since the nuclear reactor accident at Chernobyl in 1986. Farahati et al (2000) analyzed the association between disease severity (TNM classification) and age at **radiation** exposure. They found the severity of disease was associated inversely with age at the time of **radiation** exposure.

**3.18 PSYCHIATRIC**

**3.18.2** CLINICAL EFFECTS

**A)** ANXIETY

**1)** Anxiety, fear, and apprehension may be present secondary to the knowledge of exposure or may be part of neurologic symptoms secondary to CNS injury.

**3.20 REPRODUCTIVE**

**3.20.1** SUMMARY

**A)** In addition to an increased risk of cancer, exposure to ionizing **radiation** is known to affect human reproduction.

**B)** Prenatal ionizing **radiation** exposure may cause congenital anomalies, mental retardation, and an increased incidence of seizures.

**3.20.2** TERATOGENICITY

**A)** CONGENITAL ANOMALY

**1)** Four major effects of ionizing **radiation** on the fetus include: growth retardation; severe congenital malformations (including errors of metabolism); embryonic, fetal, or neonatal death; and carcinogenesis. The most pronounced permanent growth retardation occurs following irradiation in the fetal period (Jarrett, 1999).

**a)** When the fetus is irradiated during organogenesis, the peak incidence of teratogenesis occurs. In humans, **radiation**-induced malformations of bodily structures other than the CNS are uncommon. Reports on atomic bomb survivors indicate that microcephaly may result from a free-in-air dose of 100 to 190 milliGrays.

**2)** Prenatal exposure to ionizing **radiation** is well known to induce birth defects in humans, as documented in the children of pregnant atomic bomb detonation survivors (Otake & Schull, 1998; Brent, 1989). However, nuclear power industry workers exposed to low-levels of ionizing **radiation** do not appear to have an increased risk of having a liveborn child with a congenital anomaly (Green et al, 1997).

**a)** Exposures greater than 2 Gy can cause microcephaly and severe mental retardation. The critical dose and period of exposure for microcephaly is at least 0.10 to 0.19 Gy at 4 to 17 weeks, and for mental retardation is at least 0.2 to 0.4 Gy at 8 to 15 weeks (Miller, 1990). Other kinds of effects described in the literature are retarded growth, pre- and post-natal death, structural malformations, and functional impairment.

**b)** The developing fetus is most vulnerable to ionizing **radiation** at 8 to 15 weeks postconception (Ikenoue et al, 1993; Otake & Schull, 1998). There is a second period of somewhat reduced vulnerability at 18 to 27 weeks of gestation (Ikenoue et al, 1993).

**3)** Two children conceived while their mothers were undergoing I-131 therapy for thyroid cancer were born with fatal birth defects (Smith et al, 1994).

**4)** An increased prevalence of Down's syndrome (trisomy 21) has been suggested but not confirmed to be associated with periods of increased environmental ionizing **radiation** (Bound et al, 1995; Verger, 1997).

**a)** A cluster of DOWN'S SYNDROME (trisomy 21) cases was seen in the Lothian region of Scotland in 1987, temporally associated with the Chernobyl incident in April, 1986. This was unlikely to have been due to chance, but could not be readily explained by the documented low **radiation** exposure in that region (Ramsay et al, 1991). A significant increase in cases of Down's syndrome was noted in Germany after the Chernobyl disaster, with the highest rates in the most contaminated regions (Sperling et al, 1991).

**5)** Maternal mediated neonatal and developmental toxicity resulted in mouse pups after maternal intake of cesium in drinking water (Messiha, 1994).

**6)** LOW-LEVEL IONIZING **RADIATION** - Offspring of men and women occupationally exposed to low-level ionizing **radiation** were studied to determine any increased risk of congenital malformations. No evidence of a link between exposure before conception and increased risk of adverse reproductive outcome was noted in men (n=11697) or women (n=1903) (Doyle et al, 2000).

**7)** The mechanism of neurological defects may involve **radiation**-induced cell death.

**B)** MENTAL DEFICIENCY

**1)** Exposures in the range of 0.01 to 0.1 Gy may produce mental retardation and increase the risk for childhood cancers. No gross malformations seem to occur at exposures less than about 0.05 Gy (REPROTOX , 1999). The developing central nervous system may be the most sensitive target for the effects of ionizing **radiation**, with the critical period being between the 10th and 17th weeks of pregnancy (Mole, 1985; Cockerham & Prell, 1989).

**2)** Studies of the offspring of pregnant atomic bomb survivors have found mental retardation at exposures of less than 0.05 Gy, with NO

APPARENT THRESHOLD (Otake & Schull, 1998). The probability of mental retardation in this population was 40 percent per gray of fetal tissue dose (Otake & Schull, 1984). Expressed another way, there was a reduction of 21 to 29 IQ points per Gy of exposure (Miller, 1990). The frequency of mental retardation increased from a background of 0.8 to 46 percent with prenatal exposure to 1 Gray (Gy) or greater in children of atom bomb detonation survivors (Ikenoue et al, 1993). Special note should be made of the fact that these were acute exposures, which in general have more severe biological effects than equivalent doses delivered over a longer period of time.

**a)** In a cohort of 888 children whose mothers were exposed to ionizing **radiation** from atom bomb detonations, those who were exposed at 8 to 15 weeks postovulation had significantly worse scores on repetitive action tests. Those exposed at 0 to 7 weeks postovulation had decreased IQ's (Yoshimaru et al, 1995). These effects were not seen in children whose mothers were exposed at weeks 16 to 25 postovulation.

**b)** Severe mental retardation has been described in children exposed in utero to ionizing **radiation** from atomic bomb detonations at gestation ages 8 to 15 weeks (Mole, 1990).

**C)** ANIMAL STUDIES

**1)** Many similar effects in the offspring have been produced in laboratory animals, such as low birth weight and behavioral changes including hyperactivity (Norton, 1986). In experimental animal studies, induction of structural malformations has been seen, but these are lacking in exposed humans (Mole, 1987).

**2)** Fetal Swiss albino mice had different effects from a single 0.5 Gy dose of gamma **radiation** given at different times of gestation. Dosing during the preimplantation period increased prenatal mortality. Exposure between days 2 and 4 produced increased resorptions. Dosing between days 9 and 13 resulted in small heads, low brain weight, and microphthalmia (Devi & Baskar, 1996).

**3)** Prenatal exposure to ionizing **radiation** produced an increased risk of cancer and reproductive defects in mice. Female mice exposed to 1.0 and 2.7 Gy of Cf(252) and Co(60) in utero had an increased incidence of tumors of the pituitary gland, mammary gland, liver, and lung for up to two years; as well as dysfunctional ovaries (Nitta et al, 1992).

**3.20.3** EFFECTS IN PREGNANCY

**A)** SPONTANEOUS ABORTION

**1)** Increased incidences of spontaneous abortions and toxicosis of pregnancy have been seen following maternal **radiation** exposure, especially in women affected by the Chernobyl incident (Lieberman et al, 1990).

**B)** OTHER

**1)** Commercial and military flightcrew members have exposure to cosmic **radiation** greater than that of the general public, which may be of concern during pregnancy (Geeze, 1998).

**C)** LACK OF EFFECT

**1)** Use of video display terminals by pregnant women does not appear to represent a significant source of **radiation** to the fetus. Available data do not support a teratogenic risk. As field strength decreases significantly with distance, it may be prudent for pregnant women to sit at least 50 cm from the screen (Paul, 1993).

**2)** The reproductive risk from therapeutic doses of I-131 are low: in 3 studies there were no excess malformations, stillbirths, or early deaths (Dottorini, 1996).

**3.20.4** EFFECTS DURING BREAST-FEEDING

**A)** BREAST MILK

**1)** Cesium has been shown to penetrate the human placenta and breast milk in mothers following exposures (Messiha, 1994).

**3.20.5** FERTILITY

**A)** STILLBIRTH

**1)** Parker et al (1999) reported stillbirths among offspring of male **radiation** workers (paternal preconceptional irradiation) at a nuclear reprocessing plant. A point estimate range of 0 to 31.9 (95% confidence limits) stillbirths (n=130) was calculated. These estimates are stated to be qualitatively consistent with animal models. However, Selby (2000) quantitatively compares animal studies to the **radiation** workers at the nuclear reprocessing plant and suggests a point estimate of 0.1 stillbirth caused by paternal preconceptional irradiation.

**2)** Most occupational standards for exposure to ionizing **radiation** preceded publication of findings linking low-level exposure to more subtle effects in the unborn. The National Commission for **Radiation** Protection (NCRP) has recommended a cumulative fetal dose not to exceed 0.5 rad (NCRP, 1977). Using a weighting factor of 0.25 for the gonads (ILO, 1983), this would correspond to an annual whole-body dose of 2.67 rems of gamma-**radiation**.

## 3.21 CARCINOGENICITY

**3.21.2** SUMMARY/HUMAN

**A)** Ionizing **radiation** has carcinogenic effects in many tissues.

**B)** Acute ionizing **radiation** exposure survivors have increased long-term cancer risks. A dose-response relationship exists between exposure to ionizing **radiation** and the risk for the subsequent development of cancer.

**3.21.3** HUMAN STUDIES

**A)** ATOMIC BOMB SURVIVORS

**1)** GENERAL

**a)** Survivors of acute exposures have long-term risks, as seen in Japanese atomic bomb survivors. There is a dose-response relationship between exposure to ionizing **radiation** and risk for cancer. **Radiation**-induced tumors among atomic bomb detonation survivors include acute leukemia, thyroid cancer, breast cancer, lung cancer, gastric cancer, colon cancer and skin cancer (Shintani et al, 1997). The major toxicity of low- and moderate-dose ionizing **radiation** is cancer induction (Schneider & Burkart, 1998; Broerse & Dennis, 1990; Chau, 1987). There is a significantly reduced risk of developing cancer with increasing age at the time of exposure (Little et al, 1998).

**b)** All atomic bomb-related cancers have had a **radiation** dose dependence, but the shape of the dose-response curves differs with different cancers, suggesting that the mechanism(s) of **radiation**-induced cancers is complex. Although dosimetry is still being refined, in general the risk of developing cancer was significant if the dose was 100 rads or greater. The first 30 years of follow-up of the Japanese atomic bomb survivors are published in Okada et al (1975).

**c)** LEUKEMIA

**1)** LEUKEMIAS were the first evident cancers in atomic bomb survivors, with incidence peaking 7 to 8 years after exposure. The incidence of both acute and chronic leukemias was elevated, except for the notable absence of chronic lymphocytic leukemia (Little, 1993). The peak onset for acute leukemias was age-dependent, with incidence reaching a maximum at an age corresponding to approximately 1.5 times the age of the subject at the time of exposure. The time of onset for chronic leukemias did not have such a striking age effect; the difference in time of onset for different age groups was only about 3 years. The

incidence of all leukemias has subsided with time, but it is not clear if the risk for leukemia has declined to background values.

**a)** With the decline of leukemias, the onset of other types of cancer has become apparent in atomic bomb survivors. To date there is a clearly increased risk for cancers of the THYROID, BREAST (female), and LUNG. Stomach cancer and cancers of the salivary gland are suspected but not yet confirmed. In contrast to the leukemias, the time of onset for breast cancer has not been earlier than expected. Rather, breast cancer has appeared at a higher, dose-related frequency at the ages when it usually occurs.

**b)** All these cancers have had a **radiation** dose dependence, but the shape of the dose-response curves differs for different cancers, suggesting that the mechanism(s) of **radiation**-induced cancers is complex and perhaps different for different cancers. Although the dosimetry is still being refined, in general the risk for cancer was significant if the dose was 1 Gy or greater. The first 30 years of follow-up of this population are published in Okada et al (1975).

**2)** Deaths from cancer in relation to **radiation** exposure have been analyzed in the UK National Registry for **Radiation** Workers (Kendall et al, 1992). Significant elevation was seen for leukemias (excluding chronic lymphatic). Resulting lifetime risk was 10.0 percent per Sv for all cancers, and 0.76 percent per Sv for leukemia (excluding chronic lymphatic). These risks are somewhat higher than those proposed by the International Commission on Radiological Protection. There was no association seen with prostate cancer.

**3)** Draper et al (1997) concluded that the hypothesis of paternal preconception irradiation being a cause of childhood leukemia and non-Hodgkins lymphoma was NOT supported based on a case control study of 35,949 children diagnosed with cancer together with matched controls.

**a)** Busby & Cato (1998) refute the above findings, stating that exposure to internal radioisotopes may be responsible for some cancers, which was not taken into consideration. Alexander (1998) also refutes the above findings, stating that effects of population mixing may be diluted in the workers described in the study.

**d)** MENINGIOMA

**1)** MENINGIOMA - Shintani et al (1997) reported a dose-response effect in atomic bomb detonation survivors with meningioma. Incidence of meningioma increased between 1975 and 1994 in survivors of the Hiroshima atomic bomb detonation (Shintani et al, 1997).

**e)** MUCOEPIDERMOID TUMORS

**1)** In the Life Span Study cohort of atomic bomb detonation survivors followed by the **Radiation** Effects Research Foundation, 145 tumors of the salivary glands were identified. Frequency of mucoepidermoid tumors was disproportionately high at higher **radiation** doses (p=0.04). Frequency of Warthin's tumor increased with increasing **radiation** dose (p=0.06). A causal role is suggested for ionizing **radiation** in salivary gland tumorigenesis (Saku et al, 1997).

**B)** OCCUPATIONAL EXPOSURES

**1)** Doody et al (1995) conducted a case-control study of breast cancer and employment practices among female radiologic technologists (over 105,000 female medical **radiation** workers). Breast cancer cases (n=528) were matched to approximately 5 control subjects each (n=2628). No significant increase in breast cancer with occupational ionizing **radiation** exposure was found when compared to controls.

**2)** A study of 95,673 nuclear industry workers in the USA, UK, and Canada found no association between **radiation** dose and all causes of cancer deaths (Cardis et al, 1995).

**a)** Less than 15 percent of this cohort were women and their mean cumulative **radiation** dose was 7-1/2 times less than that of men.

**b)** Mortality from multiple myeloma and leukemias (except chronic lymphocytic leukemia) was significantly related to **radiation** doses. Of 119 leukemia deaths in this cohort, 6 were in workers with cumulative exposures in the 400 millisievert range.

**c)** In these workers, there was a significantly increased risk of developing leukemia at relatively low ionizing **radiation** doses and a dose-related increased multiple myeloma mortality (Cardis et al, 1995).

**3)** In a mortality study of 15,727 white male workers at the US Los Alamos National Laboratory hired between 1943 and 1977, statistically positive dose-related trends were found for development of Hodgkin's disease, malignant brain tumors, and esophageal cancers (Wiggs et al, 1994). The brain tumors reported as the cause of death may have been metastatic rather than primary tumors (Wiggs et al, 1995).

**4)** In a cancer mortality study of 8997 male employees of Atomic Energy of Canada, workers exposed to external low-linear-energy transfer ionizing **radiation** had a positive dose-related association between exposure and death from leukemia (although this was based on only 4 deaths) (Gribbin et al, 1993).

**5)** No significant association was found between development of lung cancer and ionizing **radiation** exposure in a cohort of 5657 workers of the former Spanish Nuclear Energy Board (Junta de Energia Nuclear) in a retrospective cohort study carried out between 1954 and 1992 (Rodriquez Artalejo et al, 1997).

**a)** There was excess mortality due to malignant brain tumors in this cohort (6 observed cases).

**6)** In a nested case-control study of US Airforce personnel, there was no association between development of brain tumors and ionizing **radiation** exposure (Grayson, 1996).

**7)** In a health survey of 79,016 female certified radiologic technologists, employment in this profession was not found to increase the risk of developing breast cancer (Boice et al, 1995).

**8)** A cohort analysis was conducted to evaluate the incidence of mortality following occupational exposure to uranium and vanadium, and involved 1484 uranium mill workers employed in one of seven uranium mills for at least one year on or after January 1, 1940. The analysis showed that mortality from all malignant neoplasms was less than expected, although there were non-significant increases in mortality from trachea, bronchus, and lung cancer, and lymphatic and hematopoietic malignancies (primarily lymphosarcoma, reticulosarcoma, and Hodgkin's disease). Overall, mortality from all cancers was highest among those workers with the shortest duration of employment and lowest among those with the longest duration of employment. However, firm conclusions regarding the association between occupational exposure from uranium mills and the incidence of mortality from various cancers cannot be established due to limitations of the analysis including the small cohort size, limited power to detect a moderately increased risk for some outcomes of interest, the inability to estimate individual exposures, and the lack of smoking data (Pinkerton et al, 2004)

**C)** COMMUNITY BASED EXPOSURES

**1)** Increased occurrence of childhood and adult thyroid cancer has been documented with a 4 to 5 year latency in Belarus, the Ukraine, and the USA following releases of I-131 from the Chernobyl disaster, distant US nuclear weapons plants, US atmospheric atomic weapons detonations, and a release from the Millstone nuclear power plant in the USA (Mangano, 1996; Hamilton et al, 1987).

**a)** In a cohort of 2473 persons potentially exposed to fallout from US nuclear weapons testing, a statistically significant excess of thyroid neoplasms (both benign and malignant) was found, although only 19 persons developed these tumors (Kerber et al, 1993).

**2)** A community-based health survey, from 1944 to 1995 and involving 801 individuals who had lived downwind of a U.S. plutonium production facility located in Hanford, Washington, was conducted in order to determine the type and incidence of cancers that occurred

in the community during that time period. Of the 801 residents downwind from the plutonium plant ("downwinders"), 294 residents (36.7%) reported at least one type of cancer as compared to 43 of 423 individuals (10.2%) in a control group of patients from a medical practice in Portland, Oregon. The most commonly occurring cancers among the downwinders included breast cancer (n=53, 10.2%), thyroid cancer (n=33, 4.1%), colon cancer (n=30, 3.7%), and CNS neoplasms (n=20, 2.5%). Comparison of the incidence of thyroid cancer within this population with other populations exposed to radioactive fallout showed the incidence rates from other populations were considerably lower than those for the downwinders. The crude incidence rate (cancers per 100,000 persons per year) for the downwinders study population was 82.4% (n= 33, total study population = 801) as compared to 8% for the Chernobyl population of 4 Russian regions (n=3,004, total study population = 3,113,000). It is speculated that the increased incidence rates for the downwinders may be associated with continuous environmental contamination of radioactive iodine as well as a longer follow-up period (50 years) as compared to the population involved with the Chernobyl accident (12 years) (Grossman et al, 2003).

**3)** Possible excesses of childhood cancers have been reported in populations living near nuclear installations in Britain, particularly in Sellafield, Seascale, Dounreay, Aldermaston, Burghfield, and Harwell (Gardner, 1991; Wakeford, 1995). These associations have been reviewed from historical and analytical perspectives and an association between paternal preconception exposure and childhood leukemia was only found at Seascale (Wakeford, 1995). Some in-depth reviews conclude that childhood and adult cancer rates are NOT increased in populations living near normally-operating nuclear plants (Boice & Lubin, 1997; Wakeford & Berry, 1996).

**a)** Paternal preconception exposure to internal or external ionizing **radiation** was NOT an important risk factor for childhood cancers in children whose fathers were employed as radiologists, surgeons, veterinarians, dental surgeons, or industrial radiographers (Sorahan & Roberts, 1993; Sorahan et al, 1995; Wakeford & Berry, 1996).

**D)** RISK TO OFFSPRING

**1)** Paternal exposure to ionizing **radiation** may be associated with an increased risk of cancer in the offspring. Development of leukemia in British children in the Sellafield area has been associated with paternal exposure to whole-body penetrating ionizing **radiation** (Gardner, 1991).

**2)** Besides being associated with an increased risk for mental defects, pre-natal exposure to ionizing **radiation** also increases the risk of childhood cancer, primarily in the first 10 years of life (Mole, 1987).

**E)** PANCREATIC CANCER

**1)** Ionizing **radiation** was identified as a risk factor for pancreatic cancer in a nationwide case control study in Finland (Kauppinen et al, 1995).

**2)** In a retrospective study, an increased risk of basal cell carcinoma (but not squamous cell carcinoma) was associated with prior therapeutic **radiation** (Karagas et al, 1996).

**F)** LEUKEMIA

**1)** In a cohort study of over 46,000 children of nuclear industry employees, fewer than 3 leukemias could potentially be attributed to offspring of male employees who had accumulated a preconceptual dose of > 100 mSv. No significant trends were discovered between increasing **radiation** dose and leukemia. Findings suggested that the incidence of cancer and leukemia among children of nuclear industry workers is similar to that in the general population (Roman et al, 1999).

**2)** In a population-based cohort study of 3877 commercial jet cockpit crew, crew members flying over 5000 hours were reported to have significantly increased frequency of acute myeloid leukemia (5.1 times that expected). Increased risk of melanoma (2.4 times that expected) was also found among crew flying more than 5000 hours (Gundestrup & Storm, 1999).

**3)** A study of US radiology technologists found the relative risks for non-chronic lymphocytic leukemia was increased 6.6-fold for those working 5 or more years before 1950 and 2.6-fold for those holding patients 50 or more times for x-ray examinations. Working as a radiology technologist was not associated with the risk of non-Hodgkin's lymphoma, Hodgkin's lymphoma, chronic lymphocytic leukemia, or multiple myeloma (Linet et al, 2005).

**4)** In a study population of 2,558 uranium miners, using a stratified case-cohort sampling design, a relative risk of 1.75 (95% CI 1.10 to 2.78) was reported for all leukemias in workers with high radon exposure (110 working level months (WLM); 80th percentile) compared with low radon exposure (3 WLM; 20th percentile) and 1.98 (95% CI 1.10 to 3.59) for chronic lymphocytic leukemia. The relative risks for myeloid leukemia and Hodgkin lymphoma were elevated but not statistically significant; multiple myeloma and non-Hodgkin lymphoma were not associated with radon (Rericha et al, 2006).

**G)** BREAST CANCER

**1)** A dose-dependent increased risk for breast cancer was seen in relation to exposure to low-linear energy transfer ionizing **radiation** in a large cohort of 31,917 Canadian women exposed to fluoroscopy during treatment for tuberculosis between 1930 and 1952. The results were consistent with those of the Japanese atomic bomb survivors (Howe & McLaughlin, 1996).

**2)** MALE BREAST CANCER - The incidence of breast cancer was studied in 45,880 male atomic bomb survivors diagnosed between January 1, 1958 and December 31, 1998. Nine exposed patients were diagnosed with male breast cancer as compared with 3 non-exposed individuals diagnosed with male breast cancer, indicating a statistically significant dose-response relationship reported between exposure to ionizing **radiation** and the development of male breast cancer (Ron et al, 2005).

**H)** CANCER RISK

**1)** In a multinational retrospective study of 407,391 workers monitored for external **radiation**, the estimate of relative risk per sievert for all cancers excluding leukemia was 0.97 (95% CI 0.14 to 1.97). Relative risk for leukemia, excluding chronic lymphocytic leukemia was 1.93 (95% CI <0 to 8.47) and for solid cancers was 0.87 (95% CI 0.03 to 1.88) (Cardis et al, 2005).

**I)** AGE AT EXPOSURE AND MORTALITY

**1)** A study of age at exposure and cancer mortality was conducted in workers at the United States Department of Energy Hanford Site. There was little association between mortality and cumulative doses of ionizing **radiation** accrued at ages 15 to 34, 35 to 44, and 45 to 54. For cumulative doses accrued at 55 years and older (10 year lag), the estimated excess relative risk per sievert was 9.05 (90% CI 2.96 to 17.92) for lung cancer and 3.24 (90% CI 0.80 to 6.17) for all cancers (Wing & Richardson, 2005).

**J)** PLUTONIUM-RELATED MORTALITY

**1)** At the United States Department of Energy Hanford Site, the relationship between length of exposure to plutonium and death rates from cancer was studied. For workers 50 years and older, death rate increase per year was 2.6 +/- 2.0% for all cancer, 4.9 +/- 3.3% for cancers of tissues where plutonium deposits, 7.1 +/- 3.4% for lung cancer, and 5.9 +/- 4.8% for digestive cancer (Wing et al, 2004).

### 3.22 GENOTOXICITY

**A)** Ionizing **radiation** is genotoxic and causes breaks in the structure of DNA, resulting in mutations or chromosomal structural aberrations. Double strand breaks in the mutagenic and carcinogenic effects of **radiation** have been reported. Incorrectly rejoined break leads to DNA misrepair which in turn leads to DNA deletions and rearrangements. Large scale changes in DNA structure appear to be typical of most **radiation**-

induced mutations.
**B)** Chromosomal translocations in persons who lived in houses (up to 16 years) in Taiwan contaminated with cobalt-60 has been reported. Compared to controls (no exposure to cobalt-60), the overall translocation yield in the residents was 5 times higher. Chromosomes 2, 4 and 12 were affected in 500 metaphases per person. The FISH method for reciprocal chromosomal translocations was used (Chen et al, 2000).

**3.23 OTHER**
**3.23.2** CLINICAL EFFECTS
**A)** ONSET OF ILLNESS
**1)** Delayed, or late, effects of **radiation** may occur months to years after a wide range of **radiation** doses and dose rates. A wide variety of effects, involving almost all tissues or organs, may occur. Delayed consequences of **radiation** injury have included life shortening, carcinogenesis, cataract formation, chronic radiodermatitis, decreased fertility, and genetic mutations (Jarrett, 1999).
**a)** Gamma **radiation** doses delivered at a much lower dose rate, or in fractions over a long period of time, allows tissue repair to occur. A consequent decrease in total level of injury is expected from a single dose of the same magnitude delivered over a short period of time. Neutron-**radiation** damage does not appear to be dose-rate dependent.

**4.0 LABORATORY/MONITORING**

MONITORING PARAMETERS/LEVELS

RADIOGRAPHIC STUDIES

**4.1 MONITORING PARAMETERS/LEVELS**
**4.1.1** SUMMARY
**A)** Baseline laboratory studies should include a CBC with differential count, platelet count, and electrolyte panel. These studies should be repeated frequently in the first 48 hours postexposure.
**B)** See the MEDICAL SURVEILLANCE/LABORATORY section in the main document for more information.
**4.1.2** SERUM/BLOOD
**A)** HEMATOLOGIC
**1)** The most useful immediate laboratory procedure to evaluate marrow depression is the peripheral blood count (Jarrett, 1999). Baseline laboratory studies should include a CBC with differential count and platelet count. These studies should be repeated frequently in the first 48 hours postexposure.
**2)** LYMPHOCYTES - Absolute count is an early indicator of dose; greater than 1500/mm(3) at 48 hours postexposure indicates insignificant exposure; less than 1000/mm(3) at 24 hours or less than 500/mm(3) at 48 hours postexposure indicates severe exposure. A 50% drop in lymphocytes within 24 hours indicates significant **radiation** injury. Early therapy usually prevents nearly all deaths from marrow injury alone (Jarrett, 1999).
**a)** CHROMOSOMES - An analysis of chromosomal aberrations in peripheral blood lymphocytes is commonly used to assess **radiation** dose. Even in partial-body exposures, chromosome damage can be an excellent indicator of the absorbed dose.
**B)** BLOOD/SERUM CHEMISTRY
**1)** Serum laboratory data are not diagnostic.
**2)** The serum BUN may be elevated secondary to dehydration from vomiting and diarrhea.
**3)** Baseline laboratory studies should include a serum electrolyte panel. Monitor fluid and electrolyte status. Significant fluid and electrolyte losses will occur during a gastrointestinal syndrome.
**4.1.4** OTHER
**A)** OTHER
**1)** OTHER
**a)** Human lymphocyte antigen (HL-A) typing for possible bone marrow transplantation should be done early in the course of those patients in whom exposure was suspected to be greater than 3 Gy (Cronkite & Wallace, 1977).
**b)** BONE MARROW BIOPSY - Measurement of the mitotic index of bone marrow may be a dose indicator. It appears to be best determined on day 4 following exposure (Andrews & Cloutier, 1965; Natl Acad Sci, 1963).
**c)** DOSIMETRY -
**1)** GEIGER-MUELLER COUNTER - is the most versatile instrument currently in use. It is particularly useful for personnel survey and decontamination, but it is of little value for alpha surveying, as most Geiger-Mueller tubes lack sufficient sensitivity. Very high **radiation** fields may partially or completely saturate the meter and give a low or even zero reading (Saenger, 1960).
**2)** SCINTILLATION DETECTORS - are available for alpha, beta, gamma, and neutron detection. These detectors are highly sensitive and reasonably reliable; saturation is not a problem. Specific crystals are required for detection of specific **radiation** (Saneger, 1960).
**3)** NEUTRON DETECTORS have very limited usefulness for the health physicist, as irradiated humans or objects will not emit neutron **radiation** (Saenger, 1960).
**d)** BIOMARKERS -
**1)** F-ratio - The F-ratio is the ratio between interchromosomal and intrachromosomal exchange type chromosomal aberrations (Sasaki et al, 1998). An F-ratio of 6 is characteristic of prior exposure to densely ionizing **radiation** (Brenner & Sachs, 1994).
**2)** Chromosomal type aberrations in peripheral blood lymphocytes may be a useful biomarker in hospital workers exposed to ionizing **radiation** (Bonassi et al, 1997).
**3)** Stable chromosome-type aberrations are a more sensitive indicator of chronic ionizing **radiation** exposure than is glycophorin A (GPA) analysis of variant erythrocytes in nuclear power workers (Tucker et al, 1997). In Chernobyl "liquidators" who later immigrated to Israel, glycophorin A antigen tests discriminated between these ionizing **radiation**-exposed workers and non-exposed persons (Goldsmith et al, 1997).
**4)** Micronuclei in peripheral blood lymphocytes significantly increase with exposure to 0.3 to 5 Gy of x-rays (Streffer et al, 1998). Automated assays can be done for this endpoint and if only B-lymphocytes are used, a **radiation** dose of only 0.1 Gy of x-rays

can be detected (Streffer et al, 1998). Workers exposed to radiative tritium in luminous paint or in the nuclear weapons industry also have an increased frequency of chromosomal aberrations in peripheral blood lymphocytes (Joksic & Spasojevic-Tisma, 1998).

**e)** CHERNOBYL SURVIVORS -

**1)** Recommendations for clinicians caring for victims of the Chernobyl disaster from the US National Chemobyl Registry Coordinating Center (Weinberg et al, 1995) -

**1)** ADULTS

**2)**

**a)** Routine physical examinations, special attention to thyroid
**b)** Regular cancer screening
**c)** Routine blood chemistry tests
**d)** Thyroid function tests
**e)** Complete blood count
**f)** Urinalysis
**g)** Long-term follow-up

**3)** CHILDREN

**4)**

**a)** Regular examinations
**b)** Thyroid examinations
**c)** Overall body growth evaluations
**d)** Long-term follow-up

**5)** CHILDREN - SUSPICION OF DISORDER

**6)**

**a)** Thyroid function tests
**b)** Complete blood count
**c)** Neuropsychiatric testing
**d)** Long-term follow-up

**2)** MONITORING

**a)** Monitor for presence of sepsis or opportunistic infections, particularly in the presence of bone marrow depression and loss of intestinal mucosa.

**b)** Monitor for neurological symptoms, including a steadily deteriorating state of consciousness with coma and/or seizures during the neurovascular syndrome following very high acute **radiation** doses (Jarrett, 1999).

### 4.2 RADIOGRAPHIC STUDIES

**A)** RADIOGRAPHIC-OTHER

**1)** BONE SCAN - Three-phase bone scanning is a helpful means of evaluating **radiation**-injured tissues in patients with local **radiation** injury. The scan can be used to assess the vascularity of the region, the extent of the injury, and the appropriate level for amputation (Mettler et al, 1987).

**B)** MRI

**1)** Magnetic resonance imaging is accurate in detecting **radiation** injury to the brain because of its extreme sensitivity to white matter edema (Curnes et al, 1986).

## 5.0 ABSTRACTS

### 5.1 CASE REPORTS

**A)** CHRONIC EFFECTS

**1)** CHERNOBYL - On April 26, 1986, 5 x 10(7) Ci of radionuclides escaped from a damaged nuclear reactor at Chernobyl, Ukraine (Behar et al, 1990).

**2)** Four clouds of radioactive particles covered areas including Finland, Sweden, France, Italy, Poland, Turkey, and Greece. The local area, within 18 miles of the reactor, contained 135,000 persons, 24,200 of whom were exposed to more than 0.35 Man-sv. (Note: the Sievert (Sv) is a unit of "dose-equivalent" that accounts for both the energy absorbed and the effectiveness of the pattern of energy absorption for producing biological effects). It is estimated that these people were exposed to an average activity of 600,000 Bq per person in the first 48 hours alone (Behar et al, 1990).

**3)** On the basis of these and other dosage estimates, experts predicted 1,500 deaths from thyroid cancer induced by iodine-131 and an excess of 30,000 to 40,000 cancer deaths from exposure to other radionuclides.

## 6.0 TREATMENT

LIFE SUPPORT

PATIENT DISPOSITION

MONITORING

ORAL EXPOSURE

EYE EXPOSURE

DERMAL EXPOSURE

ENHANCED ELIMINATION

**6.1 LIFE SUPPORT**

**A)** Support respiratory and cardiovascular function.

**6.3 PATIENT DISPOSITION**

**6.3.1** DISPOSITION/ORAL EXPOSURE

**6.3.1.1** ADMISSION CRITERIA/ORAL

**A)** Admission is required for fluid and electrolyte therapy if severe vomiting and diarrhea are present.

**B)** Patients manifesting thrombocytopenia, granulocytopenia, and/or lymphopenia require hospital admission. If the absolute lymphocyte count is less than 1200/mm(3) or 50 percent of initial baseline at 48 hours postexposure, reverse isolation is indicated.

**C)** Hospital admission is also necessary for standard indications for multiple trauma or burns associated with **radiation** exposure.

**6.3.1.2** HOME CRITERIA/ORAL

**A)** Any patient who is asymptomatic, totally decontaminated as indicated by survey, and has a normal CBC and platelet count may be safely discharged.

**B)** Follow-up instructions should include a repeat CBC in 48 hours and reevaluation following the onset of any gastrointestinal symptoms, e.g., nausea, vomiting, and diarrhea.

**6.3.1.4** PATIENT TRANSFER/ORAL

**A)** Initially, patients should be field-triaged to a facility designated for handling radioactively-contaminated patients. Other conditions (e.g., multiple trauma) may necessitate transporting patients to a trauma center.

**B)** After stabilization, decontamination, and initial evaluation, it may be necessary to transfer patients to a center where bone marrow transplantation can be performed if this procedure is warranted.

**C)** In mass casualty situations, patients with severe neurologic symptoms following whole body exposure should be placed in the "expectant" or "impending" category. These patients should be treated symptomatically with narcotics and sedatives as the prognosis is dismal.

**6.3.5** DISPOSITION/DERMAL EXPOSURE

**6.3.5.1** ADMISSION CRITERIA/DERMAL

**A)** Admission is required for fluid and electrolyte therapy if severe vomiting and diarrhea are present.

**B)** Patients manifesting thrombocytopenia, granulocytopenia, and/or lymphopenia require hospital admission. If the absolute lymphocyte count is less than 1200/mm(3) or 50 percent of initial baseline at 48 hours postexposure, reverse isolation is indicated.

**C)** Hospital admission is also necessary for standard indications for multiple trauma or burns associated with **radiation** exposure.

**6.3.5.2** HOME CRITERIA/DERMAL

**A)** Any patient who is asymptomatic, totally decontaminated as indicated by survey, and has a normal CBC and platelet count may be safely discharged.

**B)** Follow-up instructions should include a repeat CBC in 48 hours and reevaluation following the onset of any gastrointestinal symptoms, e.g., nausea, vomiting, and diarrhea.

**6.3.5.4** PATIENT TRANSFER/DERMAL

**A)** Initially, patients should be field-triaged to a facility designated for handling radioactively-contaminated patients. Other conditions (e.g., multiple trauma) may necessitate transporting patients to a trauma center.

**B)** After stabilization, decontamination, and initial evaluation, it may be necessary to transfer patients to a center where bone marrow transplantation can be performed if this procedure is warranted.

**C)** In mass casualty situations, patients with severe neurologic symptoms following whole body exposure should be placed in the "expectant" or "impending" category. These patients should be treated symptomatically with narcotics and sedatives as the prognosis is dismal.

**6.4 MONITORING**

**A)** Baseline laboratory studies should include a CBC with differential count, platelet count, and electrolyte panel. These studies should be repeated frequently in the first 48 hours postexposure.

**B)** See the MEDICAL SURVEILLANCE/LABORATORY section in the main document for more information.

**6.5 ORAL EXPOSURE**

**6.5.1** PREVENTION OF ABSORPTION/PREHOSPITAL

**A)** SUMMARY

**1)** Prehospital decontamination procedures should be performed with the advice of a **radiation** specialist.

**2)** The history obtained at the scene is of great importance. The exact type of exposure, i.e., internal versus external and partial versus whole body exposure, should be obtained.

**a)** If exposure is internal, both the route of entry (oral, inhalation, contaminated open wounds) and the specific radioactive material(s) should be determined. Monitoring exposed patients for contamination and decontamination procedures should be started. All personnel involved in handling patients should wear disposable protective clothing. The patient should be completely undressed and given a soap and water bath or shower (if the patient's condition permits and if the facility exists).

**6.5.2** PREVENTION OF ABSORPTION

**A)** GASTRIC LAVAGE

**1)** INTERNAL CONTAMINATION - Gastric lavage with small amounts of normal saline may be used for attempted removal of ingested radioactive materials (Leonard & Ricks, 1980; Voelz, 1980), but it is not recommended except on the advice of a **radiation** specialist (Milroy, 1984). Gastric lavage may be indicated for the unconscious patient who has ingested a fission product (e.g., cesium-137 or strontium-90) or a corrosion product (e.g., manganese-54 or cobalt-60) (Drum & Jankowski, 1984) and where it has occurred recently enough that the material is likely to still be in the stomach (Voelz, 1980).

**B)** ACTIVATED CHARCOAL

**1)** In-vitro studies comparing radioactive cesium binding to activated charcoal and sodium polystyrene sulfonate failed to demonstrate

any significant binding at 3 different pHs investigated. In-vitro tests were also performed comparing soluble and insoluble Prussian blue binding to radioactive cesium. On a molar basis, binding capacity at pH 7.5 was 264 mg/mmol insoluble Prussian blue and 27 mg/mmol soluble Prussian blue. Further animal testing with insoluble Prussian blue is needed before this can be recommended for decontamination of ingested cesium-137 (Verzijl et al, 1992).

**6.5.3** TREATMENT

**A)** GENERAL TREATMENT

**1)** **RADIATION** CONTAMINATION SUPPLIES (SHOULD BE AVAILABLE)

**a)**

| ITEM | USE |
|---|---|
| -Geiger-Mueller survey meter | Surveys for contamination |
| -Spare batteries | For use in Geiger-Mueller survey meter |
| -Plastic bags of all sizes | For disposing of contaminated materials |
| -Plastic sheet | Covering ventilation ducts, if necessary, and covering contaminated areas |
| -Remote handling tongs | For handling contaminated objects |
| -**Radiation** warning rope or ordinary rope, cord, etc. | For roping off and securing contaminated areas |
| -**Radiation** caution signs and labels | For labeling contaminated areas and objects |
| -Containers of various volumes | For collecting contaminated materials (i.e., liquids) |
| -Masking tape | For sealing plastic bags and other containers |
| -Schubert's solution | For skin decontamination |
| -Soap and water | For decontamination |
| -Cotton swabs | For decontamination |
| -Absorbent materials | For decontamination |
| -Waste containers (lined with removable plastic bags) | For radioactive waste disposal |
| -Rubber gloves | For handling contaminated material |
| -Shoe covers | For avoiding contamination of shoes |

**2)** DECONTAMINATION AREA CRITERIA

**a)** The patient receiving area and entrance should not interfere or block entry by patients who are not contaminated with radioactive material.

**b)** The decontamination and treatment area should be situated where **radiation** exposure to other patients is negligible.

**c)** Procedures for roping off and securing the decontamination and treatment areas should be formulated.

**d)** "Caution - Radioactive Material," "Caution - **Radiation** Area," and "Caution - Airborne Radioactivity Area" signs should be available for posting when and where appropriate.

**e)** A shower facility where the patient can be decontaminated should be established.

**f)** A special room or area should be available where the patient has access to a bed and toilet facilities.

**g)** A radioactive waste container labeled with a "Caution - Radioactive - Do Not Discard" sign should be available for use.

**h)** If possible, security measures should be formulated to control interested bystanders, spectators, and the news media.

**i)** A public information officer should be appointed whose responsibilities include releasing information and talking with interested spectators and the news media about the incident.

**3)** WASTE DISPOSAL (COLO DEPT HEALTH)

**a)** Contaminated water should be flushed into ordinary drains. Faucets should be left open to insure adequate dilution.

**b)** Contaminated disposable supplies should be put into plastic bags for disposition.

**c)** Contaminated equipment should remain in the control area until decontaminated.

**4)** In most cases, ED personnel will not know the exact isotopes involved, and isotope identification may take days (Leonard & Ricks, 1980). The likely sources for the most common isotopes or isotopes of military significance implicated in internal contamination are summarized in the following tables (Drum & Jankowski, 1984; Voelz, 1980; Jarrett, 1999):

| RADIONUCLIDE | | | TREATMENT | |
|---|---|---|---|---|
| CLASS or AGENT | EXAMPLE | LIKELY ACCIDENT SOURCES | ALERT PATIENT | UNCONSCIOUS/ AIRWAY INJURY |

| | | | | |
|---|---|---|---|---|
| Americium | . | Nuclear fallout | DTPA, EDTA in first 24-48 hr; preferably within 6 hours | DTPA, EDTA in first 24-48 hr; preferably within 6 hours |
| Iodines | Iodine 131 | Hospital; transport; nuclear reactor; laboratory | SSKI, KI, or NaI | SSKI (via NG tube) |
| Radium | Radium | FSU equip. | Magnesium sulfate lavage; Mg purgative; NH4Cl | Magnesium sulfate lavage; Mg purgative; NH4Cl |
| Tritium | Hydrogen 3 | Reactor coolant; laboratory; Nuclear weapons | Water diuresis | Water diuresis |
| Noble gas | Xenon 133 | Hospital; reactor | Air ventilation | Air ventilation |
| Diagnostic | Technetium 99m | Hospital; transports | Water diuresis | Water diuresis |
| Fission | Cesium 137 | Reactor coolant or deionizers | Emesis; purgatives; Bio-Rex 40*; Prussian blue | Emesis; purgatives; Bio-Rex 40*; Prussian blue |
| . | Strontium 90 | Reactor coolant or deionizers | Emesis; purgatives; Gaviscon** | Lavage; purgatives; Gaviscon** |
| *A strong cation exchange resin | | | | |
| **An aluminum hydroxide-magnesium carbonate antacid containing sorbitol, sodium alginate, and edetate sodium | | | | |

**5)** Other likely sources for common isotopes and those of military importance implicated in internal contamination are summarized in the following tables (Drum & Jankowski, 1984; Voelz, 1980; Jarrett, 1999):

| RADIONUCLIDE | | | TREATMENT | |
|---|---|---|---|---|
| CLASS | EXAMPLE | LIKELY ACCIDENT SOURCES | ALERT PATIENT | UNCONSCIOUS/ AIRWAY INJURY |
| Depleted uranium | . | Armor-piercing munitions; Armor; Aircraft counterweight | NaHCO3; Tubular diuretics | NaHCO3; Tubular diuretics |
| Corrosion products | Manganese 54 | Reactor coolant or deionizers | Lavage*; purgatives | Lavage*; purgatives |
| . | Cobalt 60 | Reactor coolant or deionizers; Food irradiator | Lavage*; purgatives; penicillamine | Lavage*; purgatives |
| Phosphorus | . | Laboratory tracer | Lavage; Al2O3; Oral phosphates | Lavage; Al2O3; Phosphates |
| Uranium | Uranium 238 | Metallurgic laboratories; mines; fuel rods | NaHCO3; Tubular diuretic | NaHCO3; Tubular diuretic |
| Transuranics | Plutonium 239 | Reprocessing plants; Nuclear weapons | Zn-DTPA or Ca-DTPA | Zn-DTPA or Ca-DTPA |
| . | Americium 241 | Reprocessing plants; weapons accident | Zn-DTPA | Zn-DTPA |
| * Refer to PRECAUTIONS FOR GASTRIC LAVAGE in the DECONTAMINATION section above. | | | | |

**B)** DECONTAMINATION

**1)** DECONTAMINATION, PREHOSPITAL

**a)** All personnel involved in handling contaminated patients (e.g., EMTs) should wear disposable protective clothing, including caps, masks, and shoe covers.

**b)** Decontamination should begin at the scene prior to placing the patient in an ambulance. The patient should be completely undressed and given a soap and water bath or shower (if the patient's condition permits, if the facility exists, and there is a possibility

of skin decontamination as well as ingestion).

**c)** All clothing and wash water from both the patient and attending personnel should be saved in sealed plastic containers labeled "radioactive waste".

**d)** The patient should be wrapped in a clean sheet and transported to the designated hospital.

**2)** DECONTAMINATION, EMERGENCY DEPARTMENT

**a)** TYPES OF EXPOSURE

**1)** EXTERNAL IRRADIATION

**a)** (Examples: X-rays, gamma rays, beta particles, neutrons)

**b)** With the possible exception of neutron exposure, the PATIENT IS NOT RADIOACTIVE and poses no hazard to attending persons. Depending on the degree of exposure, the patient may become quite sick and have various signs and symptoms, including nausea and vomiting.

**c)** From the standpoint of **radiation**, the patient does not require isolation or special handling procedures.

**d)** All of the patient's personal items (e.g., coins, watch, rings, belt, tie clasp) should be collected and saved. Each object should be labeled with the patient's name, body location, time, and date. These objects may be of value in assessing the amount of **radiation** received by the patient.

**2)** FOREIGN BODY, RADIOACTIVE

**a)** Examples - Pieces of metal, glass, or wood. This type of contamination usually follows an explosion and may involve particles that emit greater amounts of **radiation** than previously mentioned forms of contamination. Gamma, beta, alpha, and neutron **radiation**, or any combination thereof, are possible.

**b)** This type of accident is rare but could be the most hazardous to attending persons should it occur. The imbedded object(s) may be highly contaminated or radioactive in itself and should be removed from the patient as soon as possible. Depending on survey meter readings, remote handling tools and limited personnel exposure periods may be advised.

**c)** A person trained in the use of simple **radiation** survey instrumentation should be present with the instruments to assess the **radiation** levels emanating from the patient and the foreign body.

**d)** All of the patient's personal objects and all urine, fecal, and vomitus material should be labeled and saved for screening for radioactivity.

**3)** DECONTAMINATION BODY ENTRANCE CAVITIES

**a)** Survey for radioactivity and record results.

**b)** Make sure the cavity and not the surrounding area is really contaminated.

**c)** Evaluate and decontaminate surrounding area.

**d)** Irrigate with copious amounts of water or normal saline and gently swab with a moistened cotton-tipped applicator. Repeat irrigation and resurvey. If necessary and not irritating, use cotton-tipped applicator moistened with pHisoHex(R) or equivalent. Do not injure or break mucosa.

**e)** Resurvey for radioactivity, then repeat irrigation procedure and resurvey again.

**4)** HAIR AREAS

**a)** Survey for radioactivity and record.

**b)** Do NOT shave hair; if necessary, hair may be cut but do not injure skin. For surface contamination from an alpha-emitter, e.g., plutonium, shaving as a last resort can be extremely effective.

**c)** Wrap or position patient to avoid spread of contamination. Wash areas with pHisoHex(R) or equivalent. Dry with clean uncontaminated towel. Resurvey for radioactivity and record; repeat until decontaminated.

**d)** Rewash areas using a detergent such as Tide(R), Dreft(R), or Hemsol(R). Resurvey for radioactivity and record.

**e)** Rewash areas using very diluted hydrochloric acid (avoid concentrations that might cause acid burns). Resurvey for radioactivity and record.

**f)** In washing any contaminated area, use caution to prevent any skin abrasion.

**5)** GENERAL BODY

**a)** STEP I (repeat until contamination is removed) -

**1)** Survey entire body for radioactivity and record.

**2)** Visibly mark (e.g., with lipstick or erasable marker) very high level areas to receive priority.

**3)** Contaminated persons should shower using pHisoHex(R) or equivalent; make effort not to contaminate hairy areas if free of radioactivity initially.

**4)** Survey entire body for radioactivity again, marking highest levels found.

**5)** Repeat showering until contamination is removed, or continue to Step II.

**b)** STEP II

**1)** For general body contamination with high levels of radioactivity, localized areas of contamination usually remain. When showering becomes ineffective and localized areas of contamination remain, change to localized skin decontamination technique.

**2)** Repeat radioactivity surveys and record results frequently.

**6)** INHALATION/INGESTION EXPOSURE

**a)** Examples - Alpha, beta, gamma, and neutron **radiation**, or any combination thereof of substances in a solid, liquid, or gaseous form that emit.

**b)** Normally inhaled, ingested, or wound deposited radioactive materials, in the absence of external contamination, do not constitute an exposure hazard to attending persons. The quantities deposited are normally low. A **radiation** survey with an instrument that provides exposure-rate measurements may be used to verify the absence of any exposure hazard to personnel. Contamination problems may arise when vomiting and/or bleeding occurs and releases the radioactive material from the body. If this occurs, the patient should be handled as if he/she were externally contaminated with a radioactive liquid.

**c)** If the patient is contaminated with a vaporizing or sublimating material (e.g., tritium or iodine), there may be an airborne **radiation** hazard. The patient should be showered as quickly as possible and the clothing placed in a sealed container (i.e., polyethylene bags) so that the possibility of further airborne contamination is eliminated.

**d)** If there is the possibility that the ventilation system could spread airborne radioactivity to other areas of the hospital, the HVAC system should be shut down and/or the intake vents sealed off with plastic sheeting and tape.

**e)** All of the patient's personal objects and all urine, fecal, and vomitus material should be labeled and saved for screening for radioactivity.

**C)** HYPOTENSIVE EPISODE

**1)** SUMMARY

**a)** Infuse 10 to 20 milliliters/kilogram of isotonic fluid and keep the patient supine. If hypotension persists, administer dopamine or norepinephrine. Consider central venous pressure monitoring to guide further fluid therapy.

**2)** DOPAMINE

**a)** PREPARATION: Add 400 milligrams to 250 milliliters of normal saline or dextrose 5% in water to produce 1600 micrograms per milliliter or add 400 milligrams to 500 milliliters of normal saline or dextrose 5% in water to produce 800 micrograms per milliliter.

**b)** DOSE: Begin at 5 micrograms per kilogram per minute progressing in 5 micrograms per kilogram per minute increments as needed. Norepinephrine should be added if more than 20 micrograms/kilogram/minute of dopamine is needed.

**c)** CAUTION: If VENTRICULAR DYSRHYTHMIAS occur, decrease rate of administration. Extravasation may cause local tissue necrosis, administration through a central venous catheter is preferred.

**3)** NOREPINEPHRINE

**a)** PREPARATION: Add four milligram norepinephrine to 250 milliliters of dextrose 5% in water to produce a concentration of 16 micrograms/milliliter.

**b)** DOSE

**1)** ADULT: begin infusion at 0.5 to 1 microgram/minute and titrate to maintain adequate blood pressure (American Heart Association, 2005).

**2)** CHILD: begin infusion at 0.1 microgram/kilogram/minute and titrate to maintain adequate blood pressure.

**3)** CAUTION: Extravasation may cause local tissue ischemia, administration by central venous catheter is advised.

**D)** SEIZURE

**1)** SUMMARY

**a)** Attempt initial control with a benzodiazepine (diazepam or lorazepam). If seizures persist or recur administer phenobarbital or propofol.

**b)** Monitor for respiratory depression, hypotension and dysrhythmias. Endotracheal intubation should performed in patients with persistent seizures.

**c)** Evaluate for hypoxia, electrolyte disturbances, and hypoglycemia (or, if immediate bedside glucose testing is not available, treat with intravenous dextrose ADULT: 50 milliliters IV, CHILD: 2 milliliters/kilogram 25% dextrose).

**2)** DIAZEPAM

**a)** ADULT DIAZEPAM DOSE: 5 to 10 milligrams initially, repeat every 5 to 10 minutes as needed. Monitor for hypotension, respiratory depression and the need for endotracheal intubation. Consider a second agent if seizures persist or recur after diazepam 30 milligrams.

**b)** PEDIATRIC DIAZEPAM DOSE: 0.2 to 0.5 milligram per kilogram (5 milligrams maximum); repeat every 5 to 10 minutes as needed. Monitor for hypotension, respiratory depression and the need for endotracheal intubation. Consider a second agent if seizures persist or recur after diazepam 10 milligrams in children over 5 years or 5 milligrams in children under 5 years of age.

**c)** MAXIMUM RATE: Administer diazepam intravenously over 2 to 3 minutes (maximum rate = 5 milligrams/minute).

**3)** NO INTRAVENOUS ACCESS

**a)** DIAZEPAM may be given per rectum or intramuscularly. Recommended rectal dose is 0.2 mg/kg in adults and 0.5 mg/kg in children. LORAZEPAM may also be given intramuscularly or rectally (Manno, 2003).

**b)** MIDAZOLAM has been used intramuscularly and intranasally, particularly in children when intravenous access has not been established. PEDIATRIC MIDAZOLAM DOSE: INTRAMUSCULAR: 0.2 milligram/kilogram (maximum 7 milligrams) (Chamberlain et al, 1997); INTRANASAL: 0.2 milligram/kilogram (Lahat et al, 2000). BUCCAL midazolam, 10 milligrams, has been used in adolescents and older children (5-years-old or more) to control seizures when intravenous access was not established (Scott et al, 1999).

**4)** LORAZEPAM

**a)** MAXIMUM RATE: The rate of intravenous administration of lorazepam should not exceed 2 milligrams/minute (Prod Info lorazepam injection, 2004).

**b)** ADULT LORAZEPAM DOSE: 2 to 4 milligrams intravenously. Initial doses may be repeated in 10 minutes if seizures persist (Manno, 2003).

**c)** PEDIATRIC LORAZEPAM DOSE: 0.05 to 0.1 milligram/kilogram intravenously, (maximum 4 milligrams/dose) repeated twice at intervals of 10 to 15 minutes if seizures persist (Benitz & Tatro, 1995).

**5)** PHENOBARBITAL

**a)** ADULT PHENOBARBITAL LOADING DOSE: 20 milligrams per kilogram diluted in 0.9 percent saline given at 25 to 50 milligrams per minute.

**b)** REPEAT ADULT DOSE: An additional 10 milligrams/kilogram may be given if seizures persist or recur (Manno, 2003).

**c)** MAXIMUM SAFE ADULT PHENOBARBITAL DOSE: No maximum safe dose has been established. Patients in status epilepticus have received as much as 100 milligrams/minute until seizure control was achieved. Patients receiving high doses will require endotracheal intubation and may require vasopressor support.

**d)** PEDIATRIC PHENOBARBITAL LOADING DOSE: 15 to 20 milligrams per kilogram of phenobarbital intravenously given at a maximum rate of 25 to 50 milligrams per minute.

**e)** REPEAT PEDIATRIC DOSE: Repeat doses of 5 to 10 milligrams per kilogram may be given every 20 minutes if seizures persist.

**f)** MAXIMUM SAFE PEDIATRIC PHENOBARBITAL DOSE: No maximum safe dose has been established. Children in status epilepticus have received doses of 30 to 120 milligrams/kilogram within 24 hours. Vasopressors and mechanical ventilation were needed in many patients receiving these doses.

**g)** MONITOR: For hypotension, respiratory depression, and the need for endotracheal intubation.

**h)** NEONATAL PHENOBARBITAL LOADING DOSE: 20 to 30 milligrams/kilogram intravenously at a rate of no more than 1 milligram/kilogram per minute in patients with no preexisting phenobarbital serum concentrations.

**i)** NEONATAL PHENOBARBITAL MAINTENANCE DOSE: Repeat doses of 2.5 milligrams/kilogram every 12 hours may be given; adjust dosage to maintain serum concentrations of 20 to 40 micrograms/milliliter.

**j)** MAXIMUM SAFE NEONATAL PHENOBARBITAL DOSE: Doses of up to 20 milligrams/kilogram/minute up to a total of 30 milligrams/kilogram have been tolerated in neonates.

**k)** CAUTIONS: Adequacy of ventilation must be continuously monitored in children and adults. Intubation will be necessary with increased doses. Hypotension may develop with large doses and vasopressors may be required.

**l)** SERUM CONCENTRATION MONITORING: Monitor serum concentrations over next 12 to 24 hours for maintenance of therapeutic concentrations (20 to 40 micrograms per milliliter).

**E)** CHELATION THERAPY

**1)** Ingestion of radionuclides mandates special considerations. Following ingestion, there is usually a variable time before absorption and uptake by cells occurs. It is of utmost importance to determine the specific radionuclide ingested, inhaled, or injected when possible, as therapy with chelating, diluting, or blocking agents is determined by the radioelement(s) involved. Ideally, chelating agents should be administered as soon as possible after exposure, before significant uptake of the radionuclide occurs (Lincoln, 1976).

**2)** Chelating agents bind metals into complexes, thus preventing tissue uptake and allowing urinary excretion. Examples are calcium disodium EDTA and penicillamine, which are recommended for the treatment of radioactive lead poisoning. Succimer(R) (DMSA) might also be useful in this setting, although it is not FDA labelled for this use (Refer to the LEAD document for more information). Contact REAC/TS at Oak Ridge National Laboratories, Tennessee, for more information: (865) 576-3131 or (865) 576-1005 (24-Hour Emergency Line).

**3)** DTPA - Trisodium calcium diethylenetriaminepentaacetate (Ca-DTPA) is approximately 10 times more effective than trisodium zinc diethylenetriaminepentaacetate (Zn-DTPA) for initial chelation of transuranium ions; and should be used whenever larger body burdens of transuranics are involved (Prod Info Ca-DTPA, 2003) and is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment(Prod Info Zn-DTPA, 2003).

**4)** Ca-DTPA - is contraindicated in children, pregnant women, or patients with a nephrotic syndrome or patients with bone marrow depression. Zn-DTPA is given a Pregnancy Rating of C and the chelates do not significantly cross placental barriers. It is therefore; preferred to treat a pregnant female with an internal transuranic contamination; however because there are no adequate studies the potential benefits have to be weighed against the risk to the fetus (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**5)** ADVERSE EFFECTS - General adverse effects reported for both forms of DTPA include: nausea, vomiting, diarrhea, chills, fever, pruritus, and muscle cramps in the first 24 hours (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**6)** AMERICIUM

**a)** DTPA

**1)** GI absorption of Americium is minimal (usually insoluble); via the respiratory tract, 75% is absorbed and 10% is retained; skin wound absorption is rapid in first few days. Primary toxicity includes skeletal deposition, marrow suppression, and hepatic deposition. Chelation therapy with DTPA or EDTA is effective (Jarrett, 1999). In humans, 50 percent of body burden is removed, even when therapy has been long delayed; in rats, DTPA (diethylenetriamine pentaacetic acid) given one hour after administration of 243-Am reduced bone content to 50 percent of control value (Lincoln, 1976).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment(Prod Info Zn-DTPA, 2003).

**7)** CALIFORNIUM

**a)** DTPA

**1)** Early aerosol chelation with DTPA of estimated 20 to 30 nanocuries and catharsis with Fleet's Phospo-Soda 10 reduced uptake to below detectable level in 75 days (Lincoln, 1976).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**8)** CESIUM-137

**a)** PRUSSIAN BLUE

**1)** DOSE - 1 gram prussian blue with 100 to 200 milliliters of water orally three times daily. Optimal duration of therapy is not established, and depends on the extent of contamination. The manufacturer recommends treatment for at least 30 days (Prod Info Radiogardase(TM), 2003). Prussian blue helps to block absorption from the GI tract and prevents enterohepatic recycling (Anon, 2002).

**9)** THALLIUM

**a)** PRUSSIAN BLUE

**1)** DOSE - 1 gram prussian blue with 100 to 200 milliliters of water orally three times daily. Optimal duration of therapy is not established, and depends on the extent of contamination. The manufacturer recommends treatment for at least 30 days(Prod Info Radiogardase(TM), 2003). Prussian blue helps to block absorption from the GI tract and prevents enterohepatic recycling (Anon, 2002).

**2)** RUBIDIUM

**a)** PRUSSIAN BLUE

**1)** DOSE - 1 gram prussian blue with 100 to 200 milliliters of water orally three times daily. Optimal duration of therapy is not established, and depends on the extent of contamination. Prussian blue helps to block absorption from the GI tract and prevents enterohepatic recycling (Anon, 2002).

**10)** RARE EARTHS

**a)** DTPA

**1)** GENERAL - When rare earths are promptly complexed with DTPA, they are almost entirely excreted (Lincoln, 1976).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases

with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**11)** LUTETIUM

**a)** DTPA

**1)** When rare earths are promptly complexed with DTPA, they are almost entirely excreted (Lincoln, 1976).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**12)** CURIUM

**a)** DTPA

**1)** DTPA appeared to have prevented uptake following inhalation exposure. It is beneficial when given promptly but is not effective after curium is fixed in tissue (Lincoln, 1976).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**13)** LANTHANUM

**a)** DTPA

**1)** DTPA is 10 times more effective than EDTA. If given immediately, it may increase excretion from less than 2 percent to 60 percent (Lincoln, 1976).

**2)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as lanthanum (CDC, 2003)

**3)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**4)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**14)** LEAD

**a)** BAL (dimercaprol): 3 to 5 milligrams/kilogram/dose by deep intramuscular injection every 4 hours for 2 days; then every 4 to 6 hours for an additional 2 days; then every 4 to 12 hours for up to an additional 7 days. Watch for HYPOTENSION, HYPERPYREXIA and URTICARIA as signs of allergic response and administer antihistamines if required. Sterile abscess formation may occur at the injection site.

**b)** CALCIUM DISODIUM EDTA

**1)** The principal use of calcium disodium EDTA is in nonradioactive lead poisoning (Lincoln, 1976).

**2)** RECOMMENDATION - 75 milligrams/kilogram/day in 3 divided doses intravenously or intramuscularly for up to 5 days to maximum of 1 gram/day.

**c)** PENICILLAMINE

**1)** RECOMMENDATION - D-penicillamine 500 milligrams every 6 hours first day, 250 milligrams every 6 hours second day, 250 milligrams every 8 hours until no further chelation. Pediatric dose: 100 milligrams/kilogram to maximum of 1 gram/day. Penicillamine is also recommended in severe cases of cobalt radioactivity (Jarrett, 1999).

**d)** SUCCIMER/DMSA

**1)** INDICATIONS - Succimer (2,3-dimercaptosuccinic acid; DMSA) is an orally administered chelator approved for use in children with lead poisoning and blood lead levels above 45 micrograms/deciliter (Prod Info, 1991). It is the drug of choice for this indication, and should be considered also for adults with acute or chronic lead poisoning, in the absence of encephalopathy or protracted vomiting. It is NOT US FDA labelled for use in radioactive lead poisoning.

**2)** PEDIATRIC DOSE - Succimer is only approved for use in children. The recommended initial dose is 10 milligrams/kilogram or 350 milligrams/square meter every 8 hours for 5 days (Prod Info, 1991). The dosing interval is then increased to every 12 hours for the next 14 days. Repeat course may be given if indicated by elevated blood lead levels. A minimum of 2 weeks between courses is recommended. Liver function test should be monitored at least weekly. The capsule contents may be administered mixed in a small amount of food. Succimer may be used following EDTA and/or BAL therapy after an interval of 4 weeks.

**15)** MERCURY

**a)** PENICILLAMINE

**1)** Use of D-penicillamine for radioactive mercury (203-Hg) has been reported in rats only. Half-times of both components of excretion curves were significantly shortened by a 50 milligram dose (Lincoln, 1976).

**2)** RECOMMENDATION - D-penicillamine 500 milligrams every 6 hours first day, 250 milligrams every 6 hours second day, 250 milligrams every 8 hours until no further chelation. Pediatric dose: 100 milligrams/kilogram to maximum of 1 gram/day.

**16)** PLUTONIUM

**a)** DTPA

**1)** Plutonium has a high absorption with limited retention via the respiratory tract; minimal (usually insoluble) absorption via GI;

and limited absorption via dermal route (may form nodules). Primary toxicity is in the lung, bone and liver. Chelation with DTPA or EDTA is effective (Jarrett, 1999). DTPA reduced uptake by factor of 10 when given in the first hour postexposure (Lincoln, 1976).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**17)** POLONIUM

**a)** DIMERCAPROL

**1)** Polonium has moderate absorption and retention via the respiratory route; it has minimal absorption via the GI tract; and it has moderate absorption via skin wounds. Primary toxicity is seen in the spleen and kidneys. Treatment with lavage and dimercaprol is effective (Jarrett, 1999). Dose-rate to spleen in rats from oxathiol, a closely related compound, was 6.5 percent to 11.6 percent of dose-rate in untreated animals (Lincoln, 1976).

**2)** RECOMMENDATION - 3 to 5 milligrams/kilogram every 4 hours by deep intramuscular injection first 2 days; 2.5 to 3 milligrams/kilogram intramuscularly every 6 hours for 2 days; then 2.5 to 3 milligrams/kilogram every 12 hours for 1 week.

**18)** PROMETHIUM

**a)** DTPA

**1)** When DTPA was given within 30 minutes, body content was reduced to 14 percent of control (Lincoln, 1976).

**2)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as promethium (CDC, 2003).

**3)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**4)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**19)** SCANDIUM

**a)** DTPA

**1)** DTPA increases urinary secretion 20 to 30 times (Lincoln, 1976).

**2)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as scandium (CDC, 2003)

**3)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**4)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

ZIRCONIUM

**b)** DTPA

**1)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as zirconium (CDC, 2003)

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

NIOBIUM

**c)** DTPA

**1)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as niobium (CDC, 2003)

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**20)** URANIUM

**a)** BICARBONATE

**1)** DOSE - INTRAVENOUS - Administer 2 ampules of sodium bicarbonate (44.3 mEq each; 7.5%) in 1000 cc normal saline at

125 cc/hour or as an alternative; ORAL - give 2 bicarbonate tablets every 4 hours until the urine reaches a pH of 8 to 9. By alkalizing the urine, the risk of acute tubular necrosis is reduced (Anon, 2002).

**2)** DTPA should NOT be used as a chelator for uranium. The preferred treatment for internal contamination is by alkalizing the urine with bicarbonate to promote excretion (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

NEPTUNIUM

**b)** DTPA - NOT INDICATED

**1)** DTPA should NOT be used as a chelator for neptunium. It has been postulated that DTPA and neptunium form an unstable complex, which may increase bone deposition of this actinide (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**21)** YTTRIUM

**a)** DTPA

**1)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as yttrium (CDC, 2003).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**22)** ZINC

**a)** DTPA

**1)** DTPA increases urinary excretion 30 times over no treatment.

**2)** RECOMMENDATION - 1 gram intravenously in 250 milliliters isotonic saline or D5W; may also be given as an aerosol as a 25 percent solution via nebulizer. Irrigate wounds with 1 gram per 250 milliliters normal saline solution as needed. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**23)** IRON

**a)** DEFEROXAMINE

**1)** If free iron is present, clinical symptoms are severe (shock, coma), or the serum iron level is greater than 350 micrograms percent, deferoxamine should be administered intravenously; for patients not in shock, the intramuscular route may be used.

**2)** RECOMMENDATION

**a)** SHOCK STATE - 15 milligrams/kilogram/hour intravenously. Faster rates in boluses may lead to severe hypotension.

**b)** NONSHOCK STATE - 90 milligrams/kilogram intramuscularly, up to a maximum of 1 gram/dose every 8 hours, depending upon clinical status.

**24)** COPPER

**a)** Chelation therapy should be instituted immediately with BAL (Dimercaprol), D-penicillamine, or calcium sodium EDTA for removal of absorbed copper. The preferred agents are BAL and D-penicillamine. Succimer(R) (DMSA) is not particularly efficacious for copper chelation. If the patient is asymptomatic, laboratory confirmation may be obtained before instituting therapy.

**b)** DIMERCAPROL

**1)** RECOMMENDATION - 3 to 5 milligrams/kilogram dose by deep intramuscular injection every 4 hours for 2 days, every 4 to 6 hours for an additional 2 days, then every 4 to 12 hours for up to 7 additional days.

**2)** Adverse reactions (e.g., urticaria) may respond to diphenhydramine. Persistent hyperpyrexia is not uncommon.

**c)** PENICILLAMINE

**1)** RECOMMENDATION - 100 milligrams/kilogram/day orally in divided doses for up to 5 days on an empty stomach; for long-term therapy do not exceed 40 milligrams/kilogram/day.

**d)** CALCIUM DISODIUM EDTA

**1)** RECOMMENDATION - 75 milligrams/kilogram/24 hours deep intramuscular or slow intravenous infusion given in 3 to 6 divided doses up to 5 days; may be repeated for a second course after a minimum of 2 days; each course should not exceed a total of 500 milligrams/kilogram body weight.

**2)** COMPLICATIONS - include renal tubular necrosis so proper fluid balance must be maintained. Appropriate intravenous fluids and electrolytes should be administered intravenously.

**F)** RADIONUCLIDE BLOCKER

**1)** Ingestion of radionuclides mandates special considerations. Following ingestion, there is usually a variable period of time before absorption and uptake by cells occurs. It is of utmost importance to determine the specific radionuclide ingested, inhaled, or injected, as therapy with chelating, diluting, or blocking agents is determined by the radioelement(s) involved.

**2)** A blocking agent is a substance which saturates a tissue with a nonradioactive element, thereby reducing the uptake of the radionuclide. An example of this is potassium iodide (Lugol's solution) which reduces the uptake of radioactive iodine (I-131).

**3)** IODINE-131

**a)** LUGOL'S SOLUTION

**1)** Potassium iodide (Lugol's solution) reduces radioactive iodine uptake by the thyroid by 90 percent if given within 2 hours after exposure (Lincoln, 1976; Jarrett, 1999).

**2)** RECOMMENDATION - Mix 5 grams iodine and 10 grams potassium iodide with water to a final amount of 100 milliliters. Give 100 milligrams, 2 to 3 drops in glass of water. Alternatively, give 130 mg potassium iodide, or 0.8 milliliter Lugol's solution for adults and adolescents (Jarrett, 1999).

**4)** TECHNETIUM

**a)** LUGOL'S SOLUTION

**1)** Potassium iodide (Lugol's solution) reduces radioactive iodine uptake by the thyroid by 90 percent if given within 2 hours after exposure (Lincoln, 1976).

**2)** RECOMMENDATION - Mix 5 grams iodine and 10 grams potassium iodide with water to a final amount of 100 milliliters. Administer 100 milligrams, 2 to 3 drops in glass of water.

**5)** STRONTIUM-90
**a)** SODIUM ALGINATE
**1)** Ten grams of sodium alginate decrease absorption from the gut by a factor of 8 to 10; 1.5 grams decreases absorption from the gut by a factor of 2 (Lincoln, 1976).
**2)** RECOMMENDATION - 1.5 to 10 grams administered orally or chew 5 to 10 tablets stat; then 2 to 4 tablets administered orally or chewed every 2 to 4 hours for 24 hours.
**b)** ALUMINUM PHOSPHATE GEL
**1)** Aluminum phosphate gel reduces absorption from the gut by 87 percent (Lincoln, 1976).
**2)** Give 50 to 100 milliliters orally stat; then 40 milliliters every 1 to 2 hours.
**c)** ALUMINUM HYDROXIDE
**1)** This agent reduces absorption from the gut by 50 percent (Lincoln, 1976).
**2)** RECOMMENDATION - Give 65 milliliters orally stat; then 40 milliliters every 1 to 2 hours.
**d)** CALCIUM CARBONATE
**1)** Calcium carbonate is less effective than other agents.
**2)** RECOMMENDATION - Give 1 to 5 grams orally every 2 to 4 hours.
**6)** RUBIDIUM
**a)** CHLORTHALIDONE
**1)** Use of chlorthalidone more than doubled excretion (Lincoln, 1976).
**2)** RECOMMENDATION - 100 to 200 milligrams/day.

**G)** DILUTION
**1)** PHOSPHORUS-32
**a)** PHOSPHORUS
**1)** Isotopic dilution; 4 capsules supply 1 gram of phosphorus (Lincoln, 1976).
**2)** RECOMMENDATION - 2 capsules in a glass of water.
**b)** SODIUM PHOSPHATE
**1)** Phosphate can be used as a diluting agent in case of medical mismanagement of phosphorus-32. Oral phosphates can be given in inorganic (potassium or sodium phosphate) and organic forms (sodium glycerophosphate) (Voelz, 1980).
**2)** RECOMMENDATION - 10 to 20 milliliters diluted with water; each 10 milliliters contains 1.8 grams of sodium phosphate and 4.8 grams sodium biphosphate.
**2)** CESIUM-137
**a)** PRUSSIAN BLUE
**1)** If given within 10 minutes, Prussian blue reduced absorption from the gut by 40 percent (Lincoln, 1976).
**2)** DOSE - 1 gram prussian blue with 100 to 200 milliliters of water orally three times daily. Optimal duration of therapy is not established, and depends on the extent of contamination. The manufacturer recommends treatment for at least 30 days(Prod Info Radiogardase(TM), 2003). Prussian blue helps to block absorption from the GI tract and prevents enterohepatic recycling (Anon, 2002).
**b)** BIO-REX(R)
**1)** Bio-Rex(R) is as effective as Prussian blue in rats; resin should be nontoxic in humans as it is insoluble in water and dilute HCl (Lincoln, 1976).
**2)** RECOMMENDATION - Not determined for use in humans.
**3)** HYDROGEN
**a)** WATER
**1)** Radioactive hydrogen is rapidly incorporated into body water by isotopic dilution. Excretion can be increased 10 to 20 times by prompt treatment. Half-time of body water is reduced from 11.5 to 2.4 days with ingestion or infusion of 12.8 liters/day of fluids (Lincoln, 1976), but precautions must be observed to prevent water intoxication and dilutional hyponatremia.
**2)** RECOMMENDATION - 1 to 2 liters initially; continue to force fluids (5 to 10 liters/day) for 7 to 14 days.

**H)** ANTIBIOTIC
**1)** Prophylactic antibiotics are not recommended until WBC count drops to less than 1000/mm(3) or the patient has been exposed to moderate to severe levels of **radiation**. Broad spectrum antibiotics with activity against gram-negative bacteria should be initiated. Antibiotics directed toward gram-positive organisms need be included only in institutions where these infections are prevalent. Once infection is documented by cultures, the empiric regimen may require adjustment to provide appropriate coverage for the isolate. Therapy should be continued until the patient is afebrile for 24 hours and the ANC is greater than or equal to 0.5 x 10(9) cells/L (500 cells/mcL) (Jarrett, 1999; Conklin et al, 1983).

**I)** MYELOSUPPRESSION
**1)** The granulocytopenic time period can be decreased by administration of hematopoietic growth factors, such as filgrastim (Neupogen(R)), a granulocyte colony-stimulating factor (G-CSF), and sargramostim (Leukine(R)), a granulocyte-macrophage colony-stimulating factor (GM-CSF) after exposure to a bone marrow-suppressing dose of **radiation**. Risk of infection and subsequent complications are directly related to depth and duration of neutropenia. Treatment should be initiated within 24 to 72 hours subsequent to exposure. Recommendations for patients expected to experience severe neutropenia are as follows (Jarrett, 1999):
**a)** FILGRASTIM (G-CSF): 5 micrograms/kilogram/day either by injection or intravenous infusion for up to 2 weeks (CDC, 2003).
**b)** SARGRAMOSTIM (GM-CSF): 5 to 10 micrograms/kilogram/day subcutaneously until a desired effect of an ANC of 10 x 10(9)/liter is reached (Jarrett, 1999).
**c)** BONE MARROW TRANSPLANT - In cases of whole-body stem-cell sterility, bone marrow transplant may become necessary.

**J)** TRANSFUSION
**1)** Platelet transfusions are indicated when platelet count decreases to less than 20,000/mm(3).

**K)** ANTIEMETIC
**1)** Oral or parenteral prophylactic antiemetics, such as granisetron (Kytril(R)) or ondansetron (Zofran(R)), may be given in situations where high-dose radiological exposure is likely or unavoidable. These drugs will diminish the nausea and vomiting in a significant percentage of exposed persons; however, they will not change the degree of injury due to irradiation and they are NOT radioprotectants.
**a)** Granisetron 40 micrograms/kilogram (mcg/kg) or 3 milligrams (equivalent to 40 mcg/kg in a 75 kg patient) intravenously or intramuscularly has been used prior to **radiation** exposure. An oral dose of 2 milligrams has been recommended prior to **radiation** exposure.
**b)** Ondansetron is recommended as a single intravenous (IV) 32-milligram (mg) dose or three IV 0.15 mg/kilogram (mg/kg) doses.

The 32-mg dose is infused over 15 minutes. Alternatively, ondansetron 8-milligram (mg) oral loading doses prior to **radiation** exposure, followed by oral therapy with 4 milligrams (mg) every 6 hours or 8 mg every 8 hours for 1 to 5 days has been recommended.

**L)** SURGICAL PROCEDURE

**1)** Aggressive surgery such as amputation or extensive exploration should NOT be done to "eliminate radioactive contamination". The damage from surgery will far exceed any potential decrease in lifetime radiological exposure risk (Jarrett, 1999).

## 6.8 EYE EXPOSURE

### 6.8.1 DECONTAMINATION

**A)** Irrigate with copious amounts of water. Change to normal saline as soon as possible. Irrigation stream should go in a nose-to-temple direction, away from the medial canthus.

**B)** Survey irrigation fluid for radioactivity at frequent intervals and record results.

**C)** After decontamination, treat irrigation-induced conjunctivitis as usual.

## 6.9 DERMAL EXPOSURE

### 6.9.1 DECONTAMINATION

**A)** DERMAL DECONTAMINATION

**1)** SUMMARY

**a)** Examples: May emit alpha, beta, gamma, or neutron **radiation**, or any combination thereof; may be in the form of a solid (e.g., powder), liquid, or gas.

**b)** Establish and secure a decontamination area.

**c)** Anyone touching the patient or handling clothing may become contaminated. Rubber gloves, shoe covers, and a lab coat should be worn by all attending persons. Respiratory equipment may also be desirable depending on the chemical properties of the contaminating substance.

**d)** All contaminated objects (e.g., instruments, clothing, patient's personal items) should be labeled with the time, date, and patient's name. These objects should then be stored in a radioactive waste container that clearly displays the label: "CAUTION RADIOACTIVE - DO NOT DISCARD." Whenever possible, remote handling instruments (e.g., tongs) should be utilized when handling contaminated objects.

**e)** Following treatment and decontamination of the patient, the gloves, shoe covers, and lab coat should be removed and discarded into a radioactive waste container, followed eventually by proper cleaning or disposal. A thorough washing and scrubbing to remove any possible skin contamination should be performed on all attending personnel following care of the patient. Care should be taken not to break the skin during this procedure.

**f)** If possible, a person trained in the use of simple **radiation** survey instrumentation should be present with the instruments during the decontamination.

**2)** DECONTAMINATION PROCEDURES/UNBROKEN SKIN

**a)** STEP I - EVALUATION

**1)** Determine the areas that will be decontaminated and in what order, giving priority to skin breaks and highest levels of contamination.

**2)** Remove covering of contaminated areas to be cleaned. Survey area with a GM counter for radioactivity. Record survey results.

**b)** STEP II - DECONTAMINATION, INTACT SURFACE

**1)** Localize area of contamination with plastic sheet and tape to prevent further contamination of patient.

**2)** Gently wipe off loose contamination with gauze moistened with pHisoHex(R) or equivalent. Discard contaminated gauze into waste disposal bag.

**3)** Prepare Schubert's solution:

**1)** Tartaric acid: 3.0 g/L (0.2M)

**2)** Citric acid: 4.2 g/L (0.2M)

**3)** Disodium DTPA or EDTA: 8.0 g/L (0.2M)

**4)** Calcium chloride: 2.2 g/L (0.3M)

**a)** Adjusted to pH = 7 with concentrated NaOH.

**4)** Scrub area with Schubert's solution or another chelating agent, taking care not to break the skin.

**5)** Survey for radioactivity; if contamination persists, repeat cleansing with Shubert's solution until contamination is removed or until level of contamination does not decrease appreciably.

**6)** After removal of contamination, apply Nivea cream or equivalent and cover area.

**3)** DECONTAMINATION/SKIN BREAKS

**a)** STEP I

**1)** Survey the skin for radioactivity and record findings.

**2)** Irrigate wound with copious amounts of water, making sure no contamination is washed into the wound. Carefully decontaminate intact skin surface around wound (see Decontamination Procedure - Unbroken Skin).

**3)** Resurvey wound for radioactivity and record. Continue irrigation with water and survey until radioactivity is undetectable.

**4)** Treat wound in usual medical fashion. Do not flush wound with antiseptics unless this is a part of usual medical treatment; do not flush wound with chelating agents (e.g., Schubert's solution).

**5)** Cover wound and seal with plastic and tape, making sure covering is waterproof.

**6)** If wound contamination persists, continue to Step II.

**b)** STEP II

**1)** Be certain irrigation is no longer effective in decontaminating the wound.

**2)** Have a health physicist evaluate the internal body burden expected from the residual contamination. The health physicist, in conjunction with a surgeon, determines the feasibility and necessity of removing contaminated tissue.

**3)** If surgery is decided upon, the area around the wound is decontaminated completely. If possible, a "block dissection" of the wound is done. All tissue removed is surveyed for radioactivity. The wound is closed and covered.

**4)** At times it has been necessary to close the contaminated wound and perform the excision at a later date.

**5)** In cases of full thickness burns contaminated with radioactive material, the burns should be gently decontaminated to minimize absorption through the skin. Most radiological contaminants remain in the burn eschar when it sloughs (Jarrett, 1999).

**6.9.2** TREATMENT

**A)** GENERAL TREATMENT

**1)** **RADIATION** CONTAMINATION SUPPLIES (SHOULD BE AVAILABLE)

**a)**

| ITEM | USE |
|---|---|
| Geiger-Mueller survey meter | Surveys for contamination |
| Spare batteries | For use in Geiger-Mueller survey meter |
| Plastic bags of all sizes | For disposing of contaminated materials |
| Plastic sheet | Covering ventilation ducts, if necessary, and covering contaminated areas |
| Remote handling tongs | For handling contaminated objects |
| **Radiation** warning rope or ordinary rope, cord, etc. | For roping off and securing contaminated areas |
| **Radiation** caution signs and labels | For labeling contaminated areas and objects |
| Containers of various volumes | For collecting contaminated materials (i.e., liquids) |
| Masking tape | For sealing plastic bags and other containers |
| Schubert's solution | For skin decontamination |
| Soap and water | For decontamination |
| Cotton swabs | For decontamination |
| Absorbent materials | For decontamination |
| Waste containers (lined with removable plastic bags) | For radioactive waste disposal |
| Rubber gloves | For handling contaminated material |
| Shoe covers | For avoiding contamination of shoes |

**2)** DECONTAMINATION AREA CRITERIA

**a)** The patient receiving area and entrance should not interfere or block entry by patients who are not contaminated with radioactive material.

**b)** The decontamination and treatment area should be situated where **radiation** exposure to other patients is negligible.

**c)** Procedures for roping off and securing the decontamination and treatment areas should be formulated.

**d)** "Caution - Radioactive Material," "Caution - **Radiation** Area," and "Caution - Airborne Radioactivity Area" signs should be available for posting when and where appropriate.

**e)** A shower facility where the patient can be decontaminated should be established.

**f)** A special room or area should be available where the patient has access to a bed and toilet facilities.

**g)** A radioactive waste container labeled with a "Caution - Radioactive - Do Not Discard" sign should be available for use.

**h)** If possible, security measures should be formulated to control interested bystanders, spectators, and the news media.

**i)** A public information officer should be appointed whose responsibilities include releasing information and talking with interested spectators and the news media about the incident.

**3)** WASTE DISPOSAL (COLO DEPT HEALTH)

**a)** Contaminated water should be flushed into ordinary drains. Faucets should be left open to insure adequate dilution.

**b)** Contaminated disposable supplies should be put into plastic bags for disposition.

**c)** Contaminated equipment should remain in the control area until decontaminated.

**4)** In most cases, ED personnel will not know the exact isotopes involved, and isotope identification may take days (Leonard & Ricks, 1980). The likely sources for the most common isotopes or isotopes of military significance implicated in internal contamination are summarized in the following tables (Drum & Jankowski, 1984; Voelz, 1980; Jarrett, 1999):

| RADIONUCLIDE | | | TREATMENT | |
|---|---|---|---|---|
| CLASS or AGENT | EXAMPLE | LIKELY ACCIDENT SOURCES | ALERT PATIENT | UNCONSCIOUS/ AIRWAY INJURY |

| | | | | |
|---|---|---|---|---|
| Americium | . | Nuclear fallout | DTPA, EDTA in first 24-48 hr; preferably within 6 hours | DTPA, EDTA in first 24-48 hr; preferably within 6 hours |
| Iodines | Iodine 131 | Hospital; transport; nuclear reactor; laboratory | SSKI, KI, or NaI | SSKI (via NG tube) |
| Radium | Radium | FSU equip. | Magnesium sulfate lavage; Mg purgative; NH4Cl | Magnesium sulfate lavage; Mg purgative; NH4Cl |
| Tritium | Hydrogen 3 | Reactor coolant; laboratory; Nuclear weapons | Water diuresis | Water diuresis |
| Noble gas | Xenon 133 | Hospital; reactor | Air ventilation | Air ventilation |
| Diagnostic | Technetium 99m | Hospital; transport | Water diuresis | Water diuresis |
| Fission | Cesium 137 | Reactor coolant or deionizers | Emesis; purgatives; Bio-Rex 40*; Prussian blue | Emesis; purgatives; Bio-Rex 40*; Prussian blue |
| . | Strontium 90 | Reactor coolant or deionizers | Emesis; purgatives; Gaviscon** | Lavage; purgatives; Gaviscon** |
| *A strong cation exchange resin | | | | |
| **An aluminum hydroxide-magnesium carbonate antacid containing sorbitol, sodium alginate, and edetate sodium | | | | |

**5)** Other likely sources for common isotopes and those of military importance implicated in internal contamination are summarized in the following tables (Drum & Jankowski, 1984; Voelz, 1980; Jarrett, 1999):

| RADIONUCLIDE | | | TREATMENT | |
|---|---|---|---|---|
| CLASS | EXAMPLE | LIKELY ACCIDENT SOURCES | ALERT PATIENT | UNCONSCIOUS/ AIRWAY INJURY |
| Depleted uranium | . | Armor-piercing munitions; Armor; Aircraft counterweight | NaHCO3; Tubular diuretics | NaHCO3; Tubular diuretics |
| Corrosion products | Manganese 54 | Reactor coolant or deionizers | Lavage*; purgatives | Lavage*; purgatives |
| . | Cobalt 60 | Reactor coolant or deionizers; Food irradiator | Lavage*; purgatives; penicillamine | Lavage*; purgatives |
| Phosphorus | . | Laboratory tracer | Lavage; Al2O3; Oral phosphates | Lavage; Al2O3; Phosphates |
| Uranium | Uranium 238 | Metallurgic laboratories; mines; fuel rods | NaHCO3; Tubular diuretic | NaHCO3; Tubular diuretic |
| Transuranics | Plutonium 239 | Reprocessing plants; Nuclear weapons | Zn-DTPA or Ca-DTPA | Zn-DTPA or Ca-DTPA |
| . | Americium 241 | Reprocessing plants; weapons accident | Zn-DTPA | Zn-DTPA |
| * Refer to PRECAUTIONS FOR GASTRIC LAVAGE in the DECONTAMINATION section above. | | | | |

**B)** DECONTAMINATION

**1)** DECONTAMINATION, PREHOSPITAL

**a)** All personnel involved in handling contaminated patients (e.g., EMTs) should wear disposable protective clothing, including caps,

masks, and shoe covers.

**b)** Decontamination should begin at the scene prior to placing the patient in an ambulance. The patient should be completely undressed and given a soap and water bath or shower (if the patient's condition permits, if the facility exists, and there is a possibility of skin decontamination as well as ingestion).

**c)** All clothing and wash water from both the patient and attending personnel should be saved in sealed plastic containers labeled "radioactive waste".

**d)** The patient should be wrapped in a clean sheet and transported to the designated hospital.

**2)** DECONTAMINATION, EMERGENCY DEPARTMENT

**a)** TYPES OF EXPOSURE

**1)** EXTERNAL IRRADIATION

**a)** (Examples: X-rays, gamma rays, beta particles, neutrons)

**b)** With the possible exception of neutron exposure, the PATIENT IS NOT RADIOACTIVE and poses no hazard to attending persons. Depending on the degree of exposure, the patient may become quite sick and have various signs and symptoms, including nausea and vomiting.

**c)** From the standpoint of **radiation**, the patient does not require isolation or special handling procedures.

**d)** All of the patient's personal items (e.g., coins, watch, rings, belt, tie clasp) should be collected and saved. Each object should be labeled with the patient's name, body location, time, and date. These objects may be of value in assessing the amount of **radiation** received by the patient.

**2)** FOREIGN BODY, RADIOACTIVE

**a)** Examples - Pieces of metal, glass, or wood. This type of contamination usually follows an explosion and may involve particles that emit greater amounts of **radiation** than previously mentioned forms of contamination. Gamma, beta, alpha, and neutron **radiation**, or any combination thereof, are possible.

**b)** This type of accident is rare but could be the most hazardous to attending persons should it occur. The imbedded object(s) may be highly contaminated or radioactive in itself and should be removed from the patient as soon as possible. Depending on survey meter readings, remote handling tools and limited personnel exposure periods may be advised.

**c)** A person trained in the use of simple **radiation** survey instrumentation should be present with the instruments to assess the **radiation** levels emanating from the patient and the foreign body.

**d)** All of the patient's personal objects and all urine, fecal, and vomitus material should be labeled and saved for screening for radioactivity.

**3)** DECONTAMINATION BODY ENTRANCE CAVITIES

**a)** Survey for radioactivity and record results.

**b)** Make sure the cavity and not the surrounding area is really contaminated.

**c)** Evaluate and decontaminate surrounding area.

**d)** Irrigate with copious amounts of water or normal saline and gently swab with a moistened cotton-tipped applicator. Repeat irrigation and resurvey. If necessary and not irritating, use cotton-tipped applicator moistened with pHisoHex(R) or equivalent. Do not injure or break mucosa.

**e)** Resurvey for radioactivity, then repeat irrigation procedure and resurvey again.

**4)** HAIR AREAS

**a)** Survey for radioactivity and record.

**b)** Do NOT shave hair; if necessary, hair may be cut but do not injure skin. For surface contamination from an alpha-emitter, e.g., plutonium, shaving as a last resort can be extremely effective.

**c)** Wrap or position patient to avoid spread of contamination. Wash areas with pHisoHex(R) or equivalent. Dry with clean uncontaminated towel. Resurvey for radioactivity and record; repeat until decontaminated.

**d)** Rewash areas using a detergent such as Tide(R), Dreft(R), or Hemsol(R). Resurvey for radioactivity and record.

**e)** Rewash areas using very diluted hydrochloric acid (avoid concentrations that might cause acid burns). Resurvey for radioactivity and record.

**f)** In washing any contaminated area, use caution to prevent any skin abrasion.

**5)** GENERAL BODY

**a)** STEP I (repeat until contamination is removed) -

**1)** Survey entire body for radioactivity and record.

**2)** Visibly mark (e.g., with lipstick or erasable marker) very high level areas to receive priority.

**3)** Contaminated persons should shower using pHisoHex(R) or equivalent; make effort not to contaminate hairy areas if free of radioactivity initially.

**4)** Survey entire body for radioactivity again, marking highest levels found.

**5)** Repeat showering until contamination is removed, or continue to Step II.

**b)** STEP II

**1)** For general body contamination with high levels of radioactivity, localized areas of contamination usually remain. When showering becomes ineffective and localized areas of contamination remain, change to localized skin decontamination technique.

**2)** Repeat radioactivity surveys and record results frequently.

**6)** INHALATION/INGESTION EXPOSURE

**a)** Examples - Alpha, beta, gamma, and neutron **radiation**, or any combination thereof of substances in a solid, liquid, or gaseous form that emit.

**b)** Normally inhaled, ingested, or wound deposited radioactive materials, in the absence of external contamination, do not constitute an exposure hazard to attending persons. The quantities deposited are normally low. A **radiation** survey with an instrument that provides exposure-rate measurements may be used to verify the absence of any exposure hazard to personnel. Contamination problems may arise when vomiting and/or bleeding occurs and releases the radioactive material from the body. If this occurs, the patient should be handled as if he/she were externally contaminated with a radioactive liquid.

**c)** If the patient is contaminated with a vaporizing or sublimating material (e.g., tritium or iodine), there may be an airborne **radiation** hazard. The patient should be showered as quickly as possible and the clothing placed in a sealed container (i.e., polyethylene bags) so that the possibility of further airborne contamination is eliminated.

**d)** If there is the possibility that the ventilation system could spread airborne radioactivity to other areas of the hospital, the HVAC system should be shut down and/or the intake vents sealed off with plastic sheeting and tape.

**e)** All of the patient's personal objects and all urine, fecal, and vomitus material should be labeled and saved for screening for radioactivity.

**C)** HYPOTENSIVE EPISODE

**1)** SUMMARY

**a)** Infuse 10 to 20 milliliters/kilogram of isotonic fluid and keep the patient supine. If hypotension persists, administer dopamine or norepinephrine. Consider central venous pressure monitoring to guide further fluid therapy.

**2)** DOPAMINE

**a)** PREPARATION: Add 400 milligrams to 250 milliliters of normal saline or dextrose 5% in water to produce 1600 micrograms per milliliter or add 400 milligrams to 500 milliliters of normal saline or dextrose 5% in water to produce 800 micrograms per milliliter.

**b)** DOSE: Begin at 5 micrograms per kilogram per minute progressing in 5 micrograms per kilogram per minute increments as needed. Norepinephrine should be added if more than 20 micrograms/kilogram/minute of dopamine is needed.

**c)** CAUTION: If VENTRICULAR DYSRHYTHMIAS occur, decrease rate of administration. Extravasation may cause local tissue necrosis, administration through a central venous catheter is preferred.

**3)** NOREPINEPHRINE

**a)** PREPARATION: Add four milligram norepinephrine to 250 milliliters of dextrose 5% in water to produce a concentration of 16 micrograms/milliliter.

**b)** DOSE

**1)** ADULT: begin infusion at 0.5 to 1 microgram/minute and titrate to maintain adequate blood pressure (American Heart Association, 2005).

**2)** CHILD: begin infusion at 0.1 microgram/kilogram/minute and titrate to maintain adequate blood pressure.

**3)** CAUTION: Extravasation may cause local tissue ischemia, administration by central venous catheter is advised.

**D)** SEIZURE

**1)** SUMMARY

**a)** Attempt initial control with a benzodiazepine (diazepam or lorazepam). If seizures persist or recur administer phenobarbital or propofol.

**b)** Monitor for respiratory depression, hypotension and dysrhythmias. Endotracheal intubation should performed in patients with persistent seizures.

**c)** Evaluate for hypoxia, electrolyte disturbances, and hypoglycemia (or, if immediate bedside glucose testing is not available, treat with intravenous dextrose ADULT: 50 milliliters IV, CHILD: 2 milliliters/kilogram 25% dextrose).

**2)** DIAZEPAM

**a)** ADULT DIAZEPAM DOSE: 5 to 10 milligrams initially, repeat every 5 to 10 minutes as needed. Monitor for hypotension, respiratory depression and the need for endotracheal intubation. Consider a second agent if seizures persist or recur after diazepam 30 milligrams.

**b)** PEDIATRIC DIAZEPAM DOSE: 0.2 to 0.5 milligram per kilogram (5 milligrams maximum); repeat every 5 to 10 minutes as needed. Monitor for hypotension, respiratory depression and the need for endotracheal intubation. Consider a second agent if seizures persist or recur after diazepam 10 milligrams in children over 5 years or 5 milligrams in children under 5 years of age.

**c)** MAXIMUM RATE: Administer diazepam intravenously over 2 to 3 minutes (maximum rate = 5 milligrams/minute).

**3)** NO INTRAVENOUS ACCESS

**a)** DIAZEPAM may be given per rectum or intramuscularly. Recommended rectal dose is 0.2 mg/kg in adults and 0.5 mg/kg in children. LORAZEPAM may also be given intramuscularly or rectally (Manno, 2003).

**b)** MIDAZOLAM has been used intramuscularly and intranasally, particularly in children when intravenous access has not been established. PEDIATRIC MIDAZOLAM DOSE: INTRAMUSCULAR: 0.2 milligram/kilogram (maximum 7 milligrams) (Chamberlain et al, 1997); INTRANASAL: 0.2 milligram/kilogram (Lahat et al, 2000). BUCCAL midazolam, 10 milligrams, has been used in adolescents and older children (5-years-old or more) to control seizures when intravenous access was not established (Scott et al, 1999).

**4)** LORAZEPAM

**a)** MAXIMUM RATE: The rate of intravenous administration of lorazepam should not exceed 2 milligrams/minute (Prod Info lorazepam injection, 2004).

**b)** ADULT LORAZEPAM DOSE: 2 to 4 milligrams intravenously. Initial doses may be repeated in 10 minutes if seizures persist (Manno, 2003).

**c)** PEDIATRIC LORAZEPAM DOSE: 0.05 to 0.1 milligram/kilogram intravenously, (maximum 4 milligrams/dose) repeated twice at intervals of 10 to 15 minutes if seizures persist (Benitz & Tatro, 1995).

**5)** PHENOBARBITAL

**a)** ADULT PHENOBARBITAL LOADING DOSE: 20 milligrams per kilogram diluted in 0.9 percent saline given at 25 to 50 milligrams per minute.

**b)** REPEAT ADULT DOSE: An additional 10 milligrams/kilogram may be given if seizures persist or recur (Manno, 2003).

**c)** MAXIMUM SAFE ADULT PHENOBARBITAL DOSE: No maximum safe dose has been established. Patients in status epilepticus have received as much as 100 milligrams/minute until seizure control was achieved. Patients receiving high doses will require endotracheal intubation and may require vasopressor support.

**d)** PEDIATRIC PHENOBARBITAL LOADING DOSE: 15 to 20 milligrams per kilogram of phenobarbital intravenously given at a maximum rate of 25 to 50 milligrams per minute.

**e)** REPEAT PEDIATRIC DOSE: Repeat doses of 5 to 10 milligrams per kilogram may be given every 20 minutes if seizures persist.

**f)** MAXIMUM SAFE PEDIATRIC PHENOBARBITAL DOSE: No maximum safe dose has been established. Children in status epilepticus have received doses of 30 to 120 milligrams/kilogram within 24 hours. Vasopressors and mechanical ventilation were needed in many patients receiving these doses.

**g)** MONITOR: For hypotension, respiratory depression, and the need for endotracheal intubation.

**h)** NEONATAL PHENOBARBITAL LOADING DOSE: 20 to 30 milligrams/kilogram intravenously at a rate of no more than 1 milligram/kilogram per minute in patients with no preexisting phenobarbital serum concentrations.

**i)** NEONATAL PHENOBARBITAL MAINTENANCE DOSE: Repeat doses of 2.5 milligrams/kilogram every 12 hours may be given; adjust dosage to maintain serum concentrations of 20 to 40 micrograms/milliliter.

**j)** MAXIMUM SAFE NEONATAL PHENOBARBITAL DOSE: Doses of up to 20 milligrams/kilogram/minute up to a total of 30 milligrams/kilogram have been tolerated in neonates.

**k)** CAUTIONS: Adequacy of ventilation must be continuously monitored in children and adults. Intubation will be necessary with

increased doses. Hypotension may develop with large doses and vasopressors may be required.

**l)** SERUM CONCENTRATION MONITORING: Monitor serum concentrations over next 12 to 24 hours for maintenance of therapeutic concentrations (20 to 40 micrograms per milliliter).

**E)** CHELATION THERAPY

**1)** Ingestion of radionuclides mandates special considerations. Following ingestion, there is usually a variable time before absorption and uptake by cells occurs. It is of utmost importance to determine the specific radionuclide ingested, inhaled, or injected when possible, as therapy with chelating, diluting, or blocking agents is determined by the radioelement(s) involved. Ideally, chelating agents should be administered as soon as possible after exposure, before significant uptake of the radionuclide occurs (Lincoln, 1976).

**2)** Chelating agents bind metals into complexes, thus preventing tissue uptake and allowing urinary excretion. Examples are calcium disodium EDTA and penicillamine, which are recommended for the treatment of radioactive lead poisoning. Succimer(R) (DMSA) might also be useful in this setting, although it is not FDA labelled for this use (Refer to the LEAD management for more information). Contact REAC/TS at Oak Ridge National Laboratories, Tennessee, for more information: (865) 576-3131 or (865) 576-1005 (24-Hour Emergency Line).

**3)** AMERICIUM

**a)** DTPA

**1)** GI absorption of Americium is minimal (usually insoluble); via the respiratory tract, 75% is absorbed and 10% is retained; skin wound absorption is rapid in first few days. Primary toxicity includes skeletal deposition, marrow suppression, and hepatic deposition. Chelation therapy with DTPA or EDTA is effective (Jarrett, 1999). In humans, 50 percent of body burden is removed, even when therapy has been long delayed; in rats, DTPA (diethylenetriamine pentaacetic acid) given one hour after administration of 243-Am reduced bone content to 50 percent of control value (Lincoln, 1976)

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**4)** CASE REPORT - A worker was exposed to nitric acid, glass shards, and radioactive Americium following a chemical explosion. Chelation therapy with DTPA was initiated within 2 hours after the accident and continued for 4 years, resulting in the prevention of hepatic and skeletal deposition (Toohey, 2003).

**b)** BERKELIUM

**a)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**b)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**4)** CALIFORNIUM

**a)** DTPA

**1)** Early aerosol chelation with DTPA of estimated 20 to 30 nanocuries and catharsis with Fleet's Phospo-Soda 10 reduced uptake to below detectable level in 75 days (Lincoln, 1976).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**5)** CESIUM-137

**a)** PRUSSIAN BLUE

**1)** DOSE - 1 gram prussian blue with 100 to 200 milliliters of water orally three times daily. Optimal duration of therapy is not established, and depends on the extent of contamination. The manufacturer recommends treatment for at least 30 days (Prod Info Radiogardase(TM), 2003). Prussian blue helps to block absorption from the GI tract and prevents enterohepatic recycling (Anon, 2002).

**6)** RARE EARTHS

**a)** DTPA

**1)** When rare earths are promptly complexed with DTPA, they are almost entirely excreted (Lincoln, 1976).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**7)** LUTETIUM

**a)** DTPA

**1)** When rare earths are promptly complexed with DTPA, they are almost entirely excreted (Lincoln, 1976).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**8)** CURIUM

**a)** DTPA

**1)** DTPA appeared to have prevented uptake following inhalation exposure. It is beneficial when given promptly but is not effective after curium is fixed in tissue (Lincoln, 1976).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**9)** LANTHANUM

**a)** DTPA

**1)** DTPA is 10 times more effective than EDTA. If given immediately, it may increase excretion from less than 2 percent to 60 percent (Lincoln, 1976).

**2)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as lanthanum (CDC, 2003)

**3)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**4)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**10)** LEAD

**a)** BAL (dimercaprol): 3 to 5 milligrams/kilogram/dose by deep intramuscular injection every 4 hours for 2 days; then every 4 to 6 hours for an additional 2 days; then every 4 to 12 hours for up to an additional 7 days. Watch for HYPOTENSION, HYPERPYREXIA and URTICARIA as signs of allergic response and administer antihistamines if required. Sterile abscess formation may occur at the injection site.

**b)** CALCIUM DISODIUM EDTA

**1)** The principal use of calcium disodium EDTA is in nonradioactive lead poisoning (Lincoln, 1976).

**2)** RECOMMENDATION - 75 milligrams/kilogram/day in 3 divided doses intravenously or intramuscularly for up to 5 days to maximum of 1 gram/day.

**c)** PENICILLAMINE

**1)** RECOMMENDATION - D-penicillamine 500 milligrams every 6 hours first day, 250 milligrams every 6 hours second day, 250 milligrams every 8 hours until no further chelation. Pediatric dose: 100 milligrams/kilogram to maximum of 1 gram/day. Penicillamine is also recommended in severe cases of cobalt radioactivity (Jarrett, 1999).

**d)** SUCCIMER/DMSA

**1)** INDICATIONS - Succimer (2,3-dimercaptosuccinic acid; DMSA) is an orally administered chelator approved for use in children with lead poisoning and blood lead levels above 45 micrograms/deciliter (Prod Info, 1991). It is the drug of choice for this indication, and should be considered also for adults with acute or chronic lead poisoning, in the absence of encephalopathy or protracted vomiting. It is NOT US FDA labelled for use in radioactive lead poisoning.

**2)** PEDIATRIC DOSE - Succimer is only approved for use in children. The recommended initial dose is 10 milligrams/kilogram or 350 milligrams/square meter every 8 hours for 5 days (Prod Info, 1991). The dosing interval is then increased to every 12 hours for the next 14 days. Repeat course may be given if indicated by elevated blood lead levels. A minimum of 2 weeks between courses is recommended. Liver function test should be monitored at least weekly. The capsule contents may be administered mixed in a small amount of food. Succimer may be used following EDTA and/or BAL therapy after an interval of 4 weeks.

**11)** MERCURY

**a)** PENICILLAMINE

**1)** Use of D-penicillamine for radioactive mercury (203-Hg) has been reported in rats only. Half-times of both components of excretion curves were significantly shortened by a 50 milligram dose (Lincoln, 1976).

**2)** RECOMMENDATION - D-penicillamine 500 milligrams every 6 hours first day, 250 milligrams every 6 hours second day, 250 milligrams every 8 hours until no further chelation. Pediatric dose: 100 milligrams/kilogram to maximum of 1 gram/day.

**12)** PLUTONIUM

**a)** DTPA

**1)** Plutonium has a high absorption with limited retention via the respiratory tract; minimal (usually insoluble) absorption via GI; and limited absorption via dermal route (may form nodules). Primary toxicity is in the lung, bone and liver. Chelation with DTPA or EDTA is effective (Jarrett, 1999). DTPA reduced uptake by factor of 10 when given in the first hour postexposure (Lincoln, 1976).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at

the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003). Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**3)** CASE REPORT - A worker was dermally exposed to a plutonium nitrate solution. The solution covered the front surface of the patient's shin. Examination of the patient showed edema on the surface of his shin below the patella. The center of the burn was white-yellow, solid, and painful. Lymphangitis was observed around the exposed skin area. **Radiation** measurements of the wound surface indicated 160 to 240 counts/centimeters squared of alpha activity. One hundred and twenty becquerels were detected in 340 milliliters of urine, indicating a high level of radionuclide intake into the body. Intravenous administration of 1 gram of DTPA followed by 0.5 gram twice daily from the 2nd to the 4th days, 0.5 gram once daily from 6 to 20th days, 0.25 gram once daily from 21 to 33rd days, and no treatment on the 5th, 14th, and 24th days resulted in gradual resolution of the necrosis and lymphangitis, as well as, successful excretion of 96% of the absorbed plutonium (Khokhryakov et al, 2003).

**13)** POLONIUM

**a)** DIMERCAPROL

**1)** Polonium has moderate absorption and retention via the respiratory route; it has minimal absorption via the GI tract; and it has moderate absorption via skin wounds. Primary toxicity is seen in the spleen and kidneys. Treatment with lavage and dimercaprol is effective (Jarrett, 1999). Dose-rate to spleen in rats from oxathiol, a closely related compound, was 6.5 percent to 11.6 percent of dose-rate in untreated animals (Lincoln, 1976).

**2)** RECOMMENDATION - 3 to 5 milligrams/kilogram every 4 hours by deep intramuscular injection first 2 days; 2.5 to 3 milligrams/kilogram intramuscularly every 6 hours for 2 days; then 2.5 to 3 milligrams/kilogram every 12 hours for 1 week.

**14)** PROMETHIUM

**a)** DTPA

**1)** When DTPA was given within 30 minutes, body content was reduced to 14 percent of control (Lincoln, 1976).

**2)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as promethium (CDC, 2003).

**3)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**4)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**15)** SCANDIUM

**a)** DTPA

**1)** DTPA increases urinary secretion 20 to 30 times (Lincoln, 1976).

**2)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as scandium (CDC, 2003)

**3)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**4)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

ZIRCONIUM

**b)** DTPA

**1)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as zirconium (CDC, 2003)

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

NIOBIUM

**c)** DTPA

**1)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as niobium (CDC, 2003)

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**16)** URANIUM

**a)** BICARBONATE

**1)** DOSE - INTRAVENOUS - Administer 2 ampules of sodium bicarbonate (44.3 mEq each; 7.5%) in 1000 cc normal saline at 125 cc/hour or as an alternative; ORAL - give 2 bicarbonate tablets every 4 hours until the urine reaches a pH of 8 to 9. By alkalizing the urine, the risk of acute tubular necrosis is reduced (Anon, 2002).

**2)** DTPA should NOT be used as a chelator for uranium. The preferred treatment for internal contamination is by alkalizing the urine with bicarbonate to promote excretion (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

NEPTUNIUM

**b)** DTPA - NOT INDICATED

**1)** DTPA should NOT be used as a chelator for neptunium. It has been postulated that DTPA and neptunium form an unstable complex, which may increase bone deposition of this actinide (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**17)** YTTRIUM

**a)** DTPA

**1)** With special permission from the US Food and Drug Administration (FDA), DTPA may be used to treat patients who have been internally contaminated with a select group of radioactive materials, such as yttrium (CDC, 2003).

**2)** DOSE - Administer 1 gram of Ca-DTPA (it is the drug of choice for initial treatment) or Zn-DTPA by intravenous push over 3 to 4 minutes; or intravenous infusion in 100 to 250 milliliters Ringers Lactate, normal saline, or D5W; or by inhalation in a nebulizer (1:1 dilution with water or saline). Although approved for intramuscular injection, it is NOT recommended due to pain at the injection site (Prod Info Zn-DTPA, 2003; Prod Info Ca-DTPA, 2003).

**3)** ADMINISTRATION - DTPA should ideally be given within 6 hours of exposure, because the efficiency of chelation decreases with time. Ca-DTPA is generally preferred for the first 24 hours of treatment. After the first 24 hours, Zn-DTPA is nearly as effective as Ca-DTPA. Since Zn-DTPA is less toxic than Ca-DTPA, which causes loss of minerals such as zinc and magnesium, Zn-DTPA is generally the preferred chelator after the first 24 hours of treatment (Prod Info Zn-DTPA, 2003).

**18)** ZINC

**a)** DTPA

**1)** DTPA increases urinary excretion 30 times over no treatment.

**19)** IRON

**a)** DEFEROXAMINE

**1)** If free iron is present, clinical symptoms are severe (shock, coma), or the serum iron level is greater than 350 micrograms percent, deferoxamine should be administered intravenously; for patients not in shock, the intramuscular route may be used.

**2)** RECOMMENDATION

**a)** SHOCK STATE - 15 milligrams/kilogram/hour intravenously. Faster rates in boluses may lead to severe hypotension.

**b)** NONSHOCK STATE - 90 milligrams/kilogram intramuscularly, up to a maximum of 1 gram/dose every 8 hours, depending upon clinical status.

**20)** COPPER

**a)** Chelation therapy should be instituted immediately with BAL (Dimercaprol), D-penicillamine, or calcium sodium EDTA for removal of absorbed copper. The preferred agents are BAL and D-penicillamine. Succimer(R) (DMSA) is not particularly efficacious for copper chelation. If the patient is asymptomatic, laboratory confirmation may be obtained before instituting therapy.

**b)** DIMERCAPROL

**1)** RECOMMENDATION - 3 to 5 milligrams/kilogram dose by deep intramuscular injection every 4 hours for 2 days, every 4 to 6 hours for an additional 2 days, then every 4 to 12 hours for up to 7 additional days.

**2)** Adverse reactions (e.g., urticaria) may respond to diphenhydramine. Persistent hyperpyrexia is not uncommon.

**c)** PENICILLAMINE

**1)** RECOMMENDATION - 100 milligrams/kilogram/day orally in divided doses for up to 5 days on an empty stomach; for long-term therapy do not exceed 40 milligrams/kilogram/day.

**d)** CALCIUM DISODIUM EDTA

**1)** RECOMMENDATION - 75 milligrams/kilogram/24 hours deep intramuscular or slow intravenous infusion given in 3 to 6 divided doses up to 5 days; may be repeated for a second course after a minimum of 2 days; each course should not exceed a total of 500 milligrams/kilogram body weight.

**2)** COMPLICATIONS - include renal tubular necrosis so proper fluid balance must be maintained. Appropriate intravenous fluids and electrolytes should be administered intravenously.

**F)** RADIONUCLIDE BLOCKER

**1)** Ingestion of radionuclides mandates special considerations. Following ingestion, there is usually a variable period of time before absorption and uptake by cells occurs. It is of utmost importance to determine the specific radionuclide ingested, inhaled, or injected, as therapy with chelating, diluting, or blocking agents is determined by the radioelement(s) involved.

**2)** A blocking agent is a substance which saturates a tissue with a nonradioactive element, thereby reducing the uptake of the radionuclide. An example of this is potassium iodide (Lugol's solution) which reduces the uptake of radioactive iodine (I-131).

**3)** IODINE-131

**a)** LUGOL'S SOLUTION

**1)** Potassium iodide (Lugol's solution) reduces radioactive iodine uptake by the thyroid by 90 percent if given within 2 hours after exposure (Lincoln, 1976; Jarrett, 1999).

**2)** RECOMMENDATION - Mix 5 grams iodine and 10 grams potassium iodide with water to a final amount of 100 milliliters. Give 100 milligrams, 2 to 3 drops in glass of water. Alternatively, give 130 mg potassium iodide, or 0.8 milliliter Lugol's solution for adults and adolescents (Jarrett, 1999).

**4)** TECHNETIUM

**a)** LUGOL'S SOLUTION

**1)** Potassium iodide (Lugol's solution) reduces radioactive iodine uptake by the thyroid by 90 percent if given within 2 hours after exposure (Lincoln, 1976).

**2)** RECOMMENDATION - Mix 5 grams iodine and 10 grams potassium iodide with water to a final amount of 100 milliliters. Administer 100 milligrams, 2 to 3 drops in glass of water.

**5)** STRONTIUM-90

**a)** SODIUM ALGINATE

**1)** Ten grams of sodium alginate decrease absorption from the gut by a factor of 8 to 10; 1.5 grams decreases absorption from the gut by a factor of 2 (Lincoln, 1976).

**2)** RECOMMENDATION - 1.5 to 10 grams administered orally or chew 5 to 10 tablets stat; then 2 to 4 tablets administered orally or chewed every 2 to 4 hours for 24 hours.

**b)** ALUMINUM PHOSPHATE GEL

**1)** Aluminum phosphate gel reduces absorption from the gut by 87 percent (Lincoln, 1976).

**2)** Give 50 to 100 milliliters orally stat; then 40 milliliters every 1 to 2 hours.

**c)** ALUMINUM HYDROXIDE

**1)** This agent reduces absorption from the gut by 50 percent (Lincoln, 1976).

**2)** RECOMMENDATION - Give 65 milliliters orally stat; then 40 milliliters every 1 to 2 hours.

**d)** CALCIUM CARBONATE

**1)** Calcium carbonate is less effective than other agents.

**2)** RECOMMENDATION - Give 1 to 5 grams orally every 2 to 4 hours.

**6)** RUBIDIUM

**a)** CHLORTHALIDONE

**1)** Use of chlorthalidone more than doubled excretion (Lincoln, 1976).

**2)** RECOMMENDATION - 100 to 200 milligrams/day.

**G)** DILUTION

**1)** PHOSPHORUS-32

**a)** PHOSPHORUS

**1)** Isotopic dilution; 4 capsules supply 1 gram of phosphorus (Lincoln, 1976).

**2)** RECOMMENDATION - 2 capsules in a glass of water.

**b)** SODIUM PHOSPHATE

**1)** Phosphate can be used as a diluting agent in case of medical mismanagement of phosphorus-32. Oral phosphates can be given in inorganic (potassium or sodium phosphate) and organic forms (sodium glycerophosphate) (Voelz, 1980).

**2)** RECOMMENDATION - 10 to 20 milliliters diluted with water; each 10 milliliters contains 1.8 grams of sodium phosphate and 4.8 grams sodium biphosphate.

**2)** CESIUM-137

**a)** PRUSSIAN BLUE

**1)** If given within 10 minutes, Prussian blue reduced absorption from the gut by 40 percent (Lincoln, 1976).

**2)** DOSE - 1 gram prussian blue with 100 to 200 milliliters of water orally three times daily. Optimal duration of therapy is not established, and depends on the extent of contamination. The manufacturer recommends treatment for at least 30 days (Prod Info Radiogardase(TM), 2003). Prussian blue helps to block absorption from the GI tract and prevents enterohepatic recycling (Anon, 2002).

**b)** BIO-REX(R)

**1)** Bio-Rex(R) is as effective as Prussian blue in rats; resin should be nontoxic in humans as it is insoluble in water and dilute HCl (Lincoln, 1976).

**2)** RECOMMENDATION - Not determined for use in humans.

**3)** HYDROGEN

**a)** WATER

**1)** Radioactive hydrogen is rapidly incorporated into body water by isotopic dilution. Excretion can be increased 10 to 20 times by prompt treatment. Half-time of body water is reduced from 11.5 to 2.4 days with ingestion or infusion of 12.8 liters/day of fluids (Lincoln, 1976), but precautions must be observed to prevent water intoxication and dilutional hyponatremia.

**2)** RECOMMENDATION - 1 to 2 liters initially; continue to force fluids (5 to 10 liters/day) for 7 to 14 days.

**H)** ANTIBIOTIC

**1)** Prophylactic antibiotics are not recommended until WBC count drops to less than 1000/mm(3) or the patient has been exposed to moderate to severe levels of **radiation**. Broad spectrum antibiotics with activity against gram-negative bacteria should be initiated. Antibiotics directed toward gram-positive organisms need be included only in institutions where these infections are prevalent. Once infection is documented by cultures, the empiric regimen may require adjustment to provide appropriate coverage for the isolate. Therapy should be continued until the patient is afebrile for 24 hours and the ANC is greater than or equal to 0.5 x 10(9) cells/L (500 cells/mcL) (Jarrett, 1999; Conklin et al, 1983).

**I)** MYELOSUPPRESSION

**1)** The granulocytopenic time period can be decreased by administration of hematopoietic growth factors, such as filgrastim (Neupogen(R)), a granulocyte colony-stimulating factor (G-CSF), and sargramostim (Leukine(R)), a granulocyte-macrophage colony-stimulating factor (GM-CSF) after exposure to a bone marrow-suppressing dose of **radiation**. Risk of infection and subsequent complications are directly related to depth and duration of neutropenia. Treatment should be initiated within 24 to 72 hours subsequent to exposure. Recommendations for patients expected to experience severe neutropenia are as follows (Jarrett, 1999):

**a)** FILGRASTIM (G-CSF): 5 micrograms/kilogram/day either by injection or intravenous infusion for up to 2 weeks (CDC, 2003).

**b)** SARGRAMOSTIM (GM-CSF): 5 to 10 micrograms/kilogram/day subcutaneously until a desired effect of an ANC of 10 x 10(9)/liter is reached (Jarrett, 1999).

**c)** BONE MARROW TRANSPLANT - In cases of whole-body stem-cell sterility, bone marrow transplant may become necessary.

**J)** TRANSFUSION

**1)** Platelet transfusions are indicated when platelet count decreases to less than 20,000/mm(3).

**K)** ANTIEMETIC

**1)** Oral or parenteral prophylactic antiemetics, such as granisetron (Kytril(R)) or ondansetron (Zofran(R)), may be given in situations where high-dose radiological exposure is likely or unavoidable. These drugs will diminish the nausea and vomiting in a significant percentage of exposed persons; however, they will not change the degree of injury due to irradiation and they are NOT radioprotectants.

**a)** Granisetron 40 micrograms/kilogram (mcg/kg) or 3 milligrams (equivalent to 40 mcg/kg in a 75 kg patient) intravenously or intramuscularly has been used prior to **radiation** exposure. An oral dose of 2 milligrams has been recommended prior to **radiation** exposure.

**b)** Ondansetron is recommended as a single intravenous (IV) 32-milligram (mg) dose or three IV 0.15 mg/kilogram (mg/kg) doses. The 32-mg dose is infused over 15 minutes. Alternatively, ondansetron 8-milligram (mg) oral loading doses prior to **radiation** exposure, followed by oral therapy with 4 milligrams (mg) every 6 hours or 8 mg every 8 hours for 1 to 5 days has been recommended.

**L)** SURGICAL PROCEDURE

**1)** Aggressive surgery such as amputation or extensive exploration should NOT be done to "eliminate radioactive contamination". The damage from surgery will far exceed any potential decrease in lifetime radiological exposure risk (Jarrett, 1999).

**M)** **RADIATION** ESOPHAGITIS

**1)** **RADIATION** ESOPHAGITIS - Nifedipine in a dose of 5 milligrams sublingual (adults) may decrease the pain associated with esophagitis secondary to thoracic irradiation for cancer treatment (Finkelstein, 1986).

**N)** BURN OF SKIN

**1)** BURNS and **RADIATION** - Patients with thermal burns and concomitant **radiation** exposure have a marked increase in mortality. Aggressive marrow resuscitative therapeutic procedures may improve prognosis. The primary cause of death in these patients is infection (Jarrett, 1999).

**2)** PARTIAL-THICKNESS BURNS - Minimize irritation of area by thoroughly irrigating and cleaning. Blisters should be left closed; open blisters should be irrigated and treated as per appropriate burn protocols. In full-thickness burns, radioactive contaminants will slough in the eschar (Jarrett, 1999).

**O)** WOUND CARE

**1)** Excision is appropriate when surgically indicated. Radioactive contaminants will be in the wound surfaces and will be removed with the tissue (Jarrett, 1999).

**P)** TELEPHONE CONSULTATION

**1)** The United States Department of Energy Regional Coordinating Office should be notified as soon as possible. Advice and assistance regarding patient care can be obtained 24 hours/day from the **Radiation** Emergency Assistance Center/Training Site (REAC/TS), Oak Ridge Associated Universities, Oak Ridge, Tennessee (865) 576-3131 or (865) 576-1005 (24-Hour Emergency Line).

**Q)** HEMOPERFUSION

**1)** In vitro studies have compared charcoal hemoperfusion, Prussian blue therapy, and Resonium-A(R) for their abilities to decrease radioactivity in artificial media containing cesium-137 (Verzijl JM, Lie RL & Savelkoul TJ et al, 1990; Verzijl et al, 1992).

**a)** Insoluble Prussian blue was the best of the investigated adsorbents; after the addition of 60 milligrams to the radionuclide solution, nearly 100 percent of radioactivity was bound and could be removed.

**b)** Activated charcoal did not appear to adsorb to and remove radioactive substances.

**c)** Charcoal hemoperfusion was NOT found to be effective.

**R)** Treatment should include recommendations listed in the ORAL EXPOSURE section when appropriate.

### 6.11 ENHANCED ELIMINATION

**A)** HEMOPERFUSION

**1)** In vitro studies have compared charcoal hemoperfusion, Prussian blue therapy, and Resonium-A(R) for their abilities to decrease radioactivity in artificial media containing cesium-137 (Verzijl JM, Lie RL & Savelkoul TJ et al, 1990; Verzijl et al, 1992).

**a)** Insoluble Prussian blue was the best of the investigated adsorbents; after the addition of 60 milligrams to the radionuclide solution, nearly 100 percent of radioactivity was bound and could be removed.

**b)** Activated charcoal did not appear to adsorb to and remove radioactive substances.

**c)** Charcoal hemoperfusion was NOT found to be effective.

## 7.0 RANGE OF TOXICITY

SUMMARY

MINIMUM LETHAL EXPOSURE

MAXIMUM TOLERATED EXPOSURE

CALCULATIONS

### 7.1 SUMMARY

**A)** In man, the median lethal dose of **radiation** (LD50/60) is estimated to be 3.5 Gy.

### 7.3 MINIMUM LETHAL EXPOSURE

**A)** GENERAL/SUMMARY

**1)** In man, when no appropriate medical care is provided, the median lethal dose of **radiation**, the LD50/60 (that which will kill 50% of exposed persons within a 60-day period) is estimated to be 3.5 Grays (Jarrett, 1999). In many cases, although complete recovery may appear to occur, late somatic effects may have a higher probability of occurrence due to the **radiation** damage.

**B)** ADULT

**1)** A male industrial radiographer died following at least 14 years of over-exposure to iridium-192 (gamma **radiation**). It was estimated that he received a total average whole body dose of at least 10 Gy over several years. Death was due to acute myeloid leukemia which occurred as a result of the overexposure (Lloyd et al, 1994).

### 7.4 MAXIMUM TOLERATED EXPOSURE

**A)** CONCENTRATION LEVEL

**1)** Effects of LOCAL **radiation** exposure at various dose levels is expressed in the following table (Wagner et al, 1994):

| DOSE (Gray) | EFFECT |
|---|---|

| | |
|---|---|
| 2-3 | Mild dermal erythema, dry desquamation, complete healing |
| 3-4 | Temporary epilation |
| > 5 | Permanent epilation |
| 10-20 | Latent phase of 2-3 wk, resembles second-degree burn, painful and slow to heal |
| > 20 | Erythema & pain occur rapidly, blistering & desquamation occur in hours or days, resembles 3rd degree burn, prolonged recovery requiring grafts & possible amputation |

**2)** Effects of WHOLE-BODY **radiation** exposure at various dose levels is expressed in the following table (Wagner et al, 1994):

| DOSE (Gray) | EFFECT |
|---|---|
| 0.005 | No measurable effect; annual limit for general population |
| 0.05 | No measurable effect; annual limit for **radiation** workers |
| 0.15 | Oligospermia |
| 2 | Temporary azoospermia |
| 4 | Hematopoietic syndrome |
| 5 | Gastrointestinal syndrome, permanent sterility |
| 15 | Central nervous system syndrome and death |

**3)** Very high acute **radiation** doses are associated with an early transient incapacitation (ETI) or neurovascular syndrome. A lower limit of exposure for ETI is estimated to be 20 to 40 Grays. A latent period (return of partial functionality) is very short, ranging from several hours to 1 to 3 days. Following the latent period, a deteriorating state of consciousness with vascular instability and death is common. Seizures without increased intracranial pressure may or may not occur (Jarrett, 1999). This effect in humans has occurred during fuel reprocessing accidents.

**B)** RISK ASSESSMENT

**1)** Most regulatory standards for ionizing **radiation** exposure are based on a linear no-threshold extrapolation from the dose-response data for high doses (Fry et al, 1998).

**C)** CANCER DEATHS

**1)** CHERNOBYL - Estimates of excess cancer deaths predicted to occur from the Chernobyl disaster range from 5100 to 100,000 (Adelstein, 1987).

**2)** CANCER RISK - It is estimated that exposure to 100 milliGrays of gamma **radiation** (2 times the U.S. occupational annual limit of 0.05 Grays) may cause an 0.8% increase in lifetime risk of death from cancer (Jarrett, 1999).

**D)** DOSE RATE

**1)** The dose rate, as well as the total **radiation** dose, may be an important consideration in assessing the risk of exposure to ionizing **radiation** (Toohey, 2003; Broyles, 1989). Acute **radiation** syndrome (ARS) is a sequence of phased symptoms. Varied symptoms occur with individual **radiation** sensitivity, type of **radiation**, and the **radiation** dose absorbed. Extent of symptoms heightens and duration of each phase shortens with increasing **radiation** dose (Jarrett, 1999).

**E)** CATARACT FORMATION

**1)** Deterministic effects for cataract formation are directly dose-dependent. Intensity of the effect is directly related to dose. Ocular cataract formation may begin from 6 months to several years following exposure. The reported threshold for detectable cataract formation is 2 Sieverts for acute gamma **radiation** doses and 15 Sieverts for protracted doses. All types of ionizing **radiation** may induce cataract formation, but neutron irradiation is particularly effective in its formation, even at low doses (Jarrett, 1999).

**F)** FERTILITY

**1)** The testes and ovaries are only transiently affected by single sublethal doses of whole-body irradiation and usually regain normal function. Abrupt decreases in sperm count occur at whole-body irradiation above 120 milliGrays. At sublethal **radiation** doses a transient azoospermia will appear resulting in sterility which may last several months to several years (Jarrett, 1999).

**G)** CHRONIC **RADIATION** SYNDROME

**1)** Chronic **radiation** syndrome may develop in persons exposed to **radiation** for at least 3 years and who have received at least 1 Gray or more to the marrow. Clinical symptoms are varied and may include sleep and/or appetite disturbances, generalized weakness and fatigability, increased excitability, loss of concentration, impaired memory, mood changes, vertigo, ataxia, paresthesias, headaches, epistaxis, chills, syncopal episodes, bone pain, and hot flashes (Jarrett, 1999).

**H)** DRINKING WATER

**1)** The World Health Organization (WHO) recommended reference level is 0.1 milliSieverts from a 1-year consumption of drinking water; at levels below this reference dose, water is acceptable for human consumption (WHO, 1993).

**7.8 CALCULATIONS**

**A)** BIOLOGICAL CONVERSIONS

**1)** SI UNIT CONVERSION

**a)** TABLE (1) CONVERTING SI UNITS/NON-SI UNITS

| TO CONVERT: | | |
|---|---|---|
| FROM | TO | MULTIPLY BY |
| Becquerel (Bq) | Curie | 2.7 x 10(-11) |
| Curie (Ci) | Becquerel | 3.7 x 10(10) |
| Gray (Gy) | Rad | 100 |
| Rad (Rad) | Gray | 0.01 |
| Sievert (Sv) | Rem | 100 |
| Rem (Rem) | Sievert | 0.01 |

**b)** CONVERSION FACTORS TO OTHER UNITS (NATO , 1995) -

| NAME | SI - UNIT | CONVERSION FACTOR |
|---|---|---|
| Radioactivity | Becquerel (Bq) | 1 Bq = 2.7 x 10-11 Ci |
| Absorbed dose | Gray (Gy) | 1 Gy = 100 rad |
| Equivalent dose | Sievert (Sv) | 1 Sv = 100 rem |
| Effective dose | Sievert (Sv) | 1 Sv = 100 rem |

**1)** An SI unit may be preceded by: T=Tera=10(12); P=Peta=10(15); and E=Exa=10(18).

**c)** TABLE (2) CONVERTING NON-SI UNITS TO SI UNITS (Curies to becquerels) -

| MicroCi to KBq | | MicroCi to MBq | |
|---|---|---|---|
| MilliCi to MBq | | MilliCi to GBq | |
| Ci to GBq | | Ci to TBq | |
| 1 | 37 | 35 | 1.29 |
| 2 | 74 | 40 | 1.48 |
| 3 | 111 | 45 | 1.66 |
| 4 | 148 | 50 | 1.85 |
| 5 | 185 | 55 | 2.03 |
| 6 | 222 | 60 | 2.22 |
| 7 | 259 | 65 | 2.40 |
| 8 | 296 | 70 | 2.59 |
| 9 | 333 | 75 | 2.77 |
| 10 | 370 | 80 | 2.96 |
| 15 | 555 | 85 | 3.14 |

| | | | |
|---|---|---|---|
| 20 | 740 | 90 | 3.33 |
| 25 | 925 | 95 | 3.51 |
| 30 | 1110 | 100 | 3.70 |

**d)** The unit used to refer to a dose to entire population is the Man-Sievert (Man-Sv), which is the product of the estimated dose and the population.
**e)** The Sievert (Sv) is a unit of "dose-equivalent" that accounts for both the energy absorbed and the effectiveness of the pattern of energy absorption for producing biological effects.

**2)** CONVERSION FACTORS

**a)** UNITS OF **RADIATION**

**1)** **Radiation** absorbed dose (rad) is defined as a measure of the energy deposited in matter by ionizing **radiation**. The rad terminology is being replaced by the International System skin dose unit for **radiation** absorbed dose, the gray (Gy)(1 joule per kilogram); 1 Gy = 100 rad; 10 milligray (mGy) = 1 rad. The dose in gray measures an absorbed dose in any material. The gray is not limited to any specific **radiation**, but is used for all forms of ionizing **radiation**. The dose indicates the total amount of energy absorbed per gram of tissue. The reported exposure may be single or multiple and either of short or long duration (Jarrett, 1999).
**2)** Dose rate is the dose of **radiation** per unit of time (Jarrett, 1999).
**3)** Free-in-air dose is defined as the **radiation** measured in air at a certain point, which can be used to estimate midline tissue dose or dose to the blood-forming organs (Jarrett, 1999).
**4)** Since various **radiation** types have more effects as their energy is absorbed in tissue, this difference is adjusted by use of a quality factor (QF). The dose in rads times the QF yields the rem, or **radiation** equivalent, man. The international unit for this **radiation** equivalency is the sievert (Sv), which is appropriately utilized when estimating long-term risks of **radiation** injury (Jarrett, 1999). Because the QF for x-ray or gamma **radiation** = 1, then for pure gamma **radiation**: 100 rad = 100 cGy = 1000 mGy = 1 Gy = 1 Sv = 100 rem.

## 8.0 KINETICS

ABSORPTION

DISTRIBUTION

METABOLISM

ELIMINATION HALF-LIFE

### 8.1 ABSORPTION

**A)** ROUTE OF EXPOSURE

**1)** Systemic contamination will occur following ingestion, inhalation, skin absorption, or wound contamination of radioactive material (Jarrett, 1999).

**a)** INHALATION - In the respiratory tract, particles less than 5 microns in diameter may be deposited in the alveolar area. The oropharynx will clear larger particles by the mucociliary apparatus. Soluble particles will be absorbed into the blood stream while insoluble particles, until cleared from the respiratory tract, will continue to irradiate surrounding tissues.
**b)** INGESTION - Absorption following ingestion is dependent on the chemical composition of the contaminant and its solubility. For example, radioiodine and cesium are rapidly absorbed while plutonium, radium, and strontium are not. The GI tract is considered a target organ for insoluble radionuclides that pass unchanged in the feces.
**c)** SKIN - The skin is impermeable to most of the radionuclides available.
**d)** WOUNDS - The epithelial barrier is bypassed when wounds and burns are present which create a portal for any particulate contamination. Fluid in a wound may hide weak beta and alpha emissions from detectors.

### 8.2 DISTRIBUTION

**8.2.1** DISTRIBUTION SITES

**A)** TISSUE/FLUID SITES

**1)** Following absorption, a radionuclide crosses capillary membranes through passive and active diffusion mechanisms and then is distributed throughout the body. Rate of distribution to each organ is dependent on organ metabolism, ease of chemical transport, and the affinity of the radionuclide for chemicals within the organ. The organs with the highest capacities for binding radionuclides are the liver, kidney, adipose tissue, and bone due to their high protein and lipid makeup (Jarrett, 1999).

### 8.3 METABOLISM

**8.3.1** METABOLISM SITES AND KINETICS

**A)** GENERAL

**1)** The metabolic pathway of a radionuclide is determined by the metabolism of its nonradioactive analog (Jarrett, 1999).

### 8.5 ELIMINATION HALF-LIFE

**8.5.1** PARENT COMPOUND

**A)** SPECIFIC SUBSTANCE

**1) Radiation** half-lives may range from less than a second to millions of years. Samples of some radionuclides and their half-lives are shown in the table below (Edsall, 1999):

| RADIONUCLIDE | HALF-LIFE |
|---|---|
| Tc-99m | 6.0 hours |
| I-131 | 8.05 days |
| Co-60 | 5.26 years |
| Sr-90 | 28.1 years |
| Pu-239 | 24,400 years |
| U-238 | 4,150,000,000 years |

## 9.0 PHARMACOLOGY/TOXICOLOGY

PHARMACOLOGIC MECHANISM

TOXICOLOGIC MECHANISM

### 9.1 PHARMACOLOGIC MECHANISM

**A)** Exposure to ionizing **radiation** results in deposition of energy in the tissues and ionization of atoms with breakdown of chemical bonds. Ion pairs form along the particle tract and determine the biologic effect (Conklin et al, 1983).

**B)** Molecule excitation and ion production cause the formation of free radicals and chemical changes in cells. DNA may be especially susceptible, leading to carcinogenicity, inheritable reproductive effects, and teratogenicity.

### 9.2 TOXICOLOGIC MECHANISM

**A)** CANCER -

**1) Radiation** exposure leads to DNA breakages, most of which are repaired properly by enzymes. If the cell is still in a dividing phase, repair failures or mistakes may be potentiated in daughter cells and establish a cancerous clone (Behar et al, 1990).

**2)** Some evidence points to a negative effect of **radiation** on T-lymphocytes, which destroy cancer cells (Behar et al, 1990).

**3) Radiation** may serve as a promoter, causing or speeding development of a cancer in tissue already preconditioned for cancer (Behar et al, 1990).

**B)** CELLULAR EFFECTS - The hematopoietic and the gastrointestinal systems are the two most radiosensitive organ systems in the body. Relative sensitivities of an organ to direct **radiation** injury is dependent on its component tissue sensitivities. Cellular effects, whether due to direct or indirect **radiation**, are basically the same for various kinds and doses of **radiation**.

**1)** The simplest cellular effect is cell death. Changes in cellular function, which occur at lower than lethal cellular **radiation** doses, may include delays in phases of the mitotic cycle, disruption of cell growth, permeability changes, and changes in motility. Actively dividing cells are most sensitive to **radiation**. Radiosensitivity tends to vary inversely with the degree of differentiation of the cell ((Anon, 2000)).

## 12.0 REFERENCES

### 12.2 GENERAL BIBLIOGRAPHY

**1)** Adelstein SJ: Uncertainty and relative risks of **radiation** exposure. JAMA 1987; 258:655-657.

**2)** American Heart Association: 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 2005; 112(24 Suppl):IV 1-203. Available from URL: http://circ.ahajournals.org/content/vol112/24_suppl/. As accessed 12/14/2005.

**3)** Andrews GA & Cloutier RJ: Accidental acute **radiation** injury. Arch Environ Health 1965; 10:498-507.

**4)** Anon : Army Field Manual FM 8-10-7. Chapter 2. Nuclear, Biological, and Chemical Weapons Effects. U.S. Army. Washington, DC, USA. 2000. Available from URL: http://www.nbc-med.org/SiteContent/ MedRef/OnlineRef/FieldManuals/fm8_107/chapter2.htm. As accessed Accessed July 12, 2000.

**5)** Anon: Managing **Radiation** Emergencies. Oak Ridge Associated Universities. Oak Ridge, TN, USA. 2002. Available from URL: www.orau.gov/reacts/internal/htm. As accessed 01/26/04.

**6)** Barquinero JF, Barrios L, & Caballin MR: Cytogenetic analysis of lymphocytes from hospital workers occupationally exposed to low levels of ionizing **radiation**. Mutat Res 1993; 286:275-279.

**7)** Becker DV: Reactor accidents: Public health strategies and their medical implications. JAMA 1987; 258:649-654.

**8)** Behar A, Cohen-Boulakia F, & Othmani S: Chernobyl three years later: radiobiologic evaluation of a radioactive contamination. J Environ Pathol Toxicol Oncol 1990; 10:281-285.

**9)** Benitz WE & Tatro DS: The Pediatric Drug Handbook, 3rd ed, Mosby-Year Book Inc, Chicago, IL, 1995.

**10)** Birioukov A, Meurer M, & Peter RU: Male reproductive system in patients exposed to ionizing irradiation in the chernobyl accident. Arch Androl 1993; 30:99-104.

**11)** Birrell GW & Ramsay JR: Induction of p53 protein by gamma **radiation** in lymphocyte lines from breast cancer and ataxia tenangiectasia patients. Br J Cancer 1995; 72:1096-1101.

**12)** Boice JD & Lubin JH: Occupational and environmental **radiation** and cancer. Cancer Causes Control 1997; 8:309-322.
**13)** Boice JD, Mandel JS, & Doody MM: Breast cancer among radiologic technologists. JAMA 1995; 274:394-401.
**14)** Bonassi S, Forni A, & Bigatti P: Chromosome aberrations in hospital workers: evidence from surveillance studies in Italy (1963-1993). Am J Ind Med 1997; 31:353-360.
**15)** Bound JP, Francis BJ, & Harvey PW: Down's syndrome: prevalence and ionising **radiation** in an area of north west England 1957-91. J Epidemiol Community Health 1995; 49:164-170.
**16)** Brandom WF: Radiat Res 1978; 76:159-171.
**17)** Brenner DJ & Sachs RK: Chromosomal "fingerprints" of prior exposure to densely ionizing **radiation**. Radiat Res 1994; 140:134-142.
**18)** Brent RL: The effects of embryonic and fetal exposure to X-ray, microwaves, and ultrasound: Counseling the pregnant and nonpregnant patient about these risks. Seminars in Oncology 1989; 16:347-368.
**19)** Broerse JJ & Dennis JA: Dosimetric aspects of exposure of the population to ionizing **radiation**. Internat J Radiat Biol 1990; 57:633-645.
**20)** Broyles AA: The effect of dose rate on **radiation** injury. Health Physics 1989; 56:933-937.
**21)** CDC: Facts about DTPA. Centers for Disease Control. Atlanta, Ga, USA. 2003a. Available from URL: cdc.gov.**radiationemergencies**. As accessed 01/26/04.
**22)** CDC: Facts about neupogen. Centers for Disease Control. Atlanta, GA, USA. 2003. Available from URL: www.bt.cdc.gov/**radiation** /neupogenfacts.asp. As accessed 01/05/04.
**23)** Cardis E, Gilbert ES, & Carpenter L: Effects of low doses and low dose rates of external ionizing **radiation**: Cancer mortality among nuclear industry workers in three countries. Radiat Res 1995; 142:117-132.
**24)** Cardis E, Vrijheid M, Blettner M, et al: Risk of cancer after low doses of ionising **radiation**: retrospective cohort study in 15 countries. BMJ 2005; 331(7508):77-.
**25)** Chamberlain JM, Altieri MA, & Futterman C: A prospective, randomized study comparing intramuscular midazolam with intravenous diazepam for the treatment of seizures in children. Ped Emerg Care 1997; 13:92-94.
**26)** Champlin RE, Kastenberg WE, & Gale RP: **Radiation** accidents and nuclear energy: Medical consequences and therapy. Ann Intern Med 1988; 109:730-744.
**27)** Chau NP: **Radiation** carcinogenesis in humans: Is it necessary to revise exposure dose limits based on recent estimates of lifetime risks?. Health Physics 1987; 52:753-761.
**28)** Checkoway H: J Occup Med 1985; 27:885-892.
**29)** Chen FD, Chen KY, & Ngo FQH: Chromosomal damage in long-term residents of houses contaminated with cobalt-60 (letter). Lancet 2000; 355:726.
**30)** Christensen J: Two reports warn of radioactive bullets. High Country Times 1993; 25:4.
**31)** Cockerham LG & Prell GD: Prenatal **radiation** risk to the brain. Neurotoxicol 1989; 10:467-474.
**32)** Conde-Salazar L, Guimaraens D, & Romero LV: Occupational radiodermatitis from Ir(192) exposure. Contact Dermatitis 1986; 15:202-204.
**33)** Conklin JJ, Walker RI, & Hirsch EF: Current concepts in the management of **radiation** injuries and associated trauma. Surg Gynecol Obstet 1983; 156:809-829.
**34)** Correia MP, Santos D, & Jorge M: Radiotherapy-induced pemphigus (Portugese). ACTA Med Port 1998; 11:581-583.
**35)** Cronkite EP & Wallace JF: **Radiation** and electrical injuries, in: Isselbacher KJ, Adams RD, Braunwald E et al (Eds), Harrison's Principles of Internal Medicine, 8th ed, McGraw Hill, New York, NY, 1977, pp 748-752.
**36)** Curnes JT, Laster DW, & Ball MR: Magnetic resonance imaging of **radiation** injury to the brain. Am J Neuroradiol 1986; 7:389-394.
**37)** Dacruz AD, Volpe JP, & Saddi V: **Radiation** risk estimation in human populations -- lessons from the radiological accident in Brazil. Mutat Res 1997; 373:207-214.
**38)** Devi PU & Baskar R: Influence of gestational age at exposure on the prenatal effects of gamma-**radiation**. Internat J Radiat Biol 1996; 70:45-52.
**39)** Diffre P: Radionuclides in the environment. J Environ Pathol Toxicol Oncol 1990; 10:276-280.
**40)** Dottorini ME: Genetic risk assessment after iodine-131 exposure: an opportunity and obligation for nuclear medicine. J Nucl Med 1996; 37:612-615.
**41)** Doyle P, Maconochie N, & Roman E: Fetal death and congenital malformation in babies born to nuclear industry employees: report from the nuclear industry family study. Lancet 2000; 356:1293-1299.
**42)** Drum DE & Jankowski CB: **Radiation** injury, in: May HL (Ed), Emergency Medicine, John Wiley & Sons, New York, NY, 1984, pp 491-498.
**43)** Dunn K, Yoshimaru H, & Otake M: Prenatal exposure to ionizing **radiation** and subsequent development of seizures. Am J Epidemiol 1990; 131:114-123.
**44)** Edsall K: **Radiation** exposure, North American Congress of Clinical Toxicology, Orlando, FL, 1999.
**45)** Emerit I, Oganesian N, & Sarkisian T: Clastogenic factors in the plasma of Chernobyl accident recovery workers -- anticlastogenic effect of Ginkgo biloba extract. Radiat Res 1995; 144:198-205.
**46)** Finch SC: Acute **radiation** syndrome. JAMA 1987; 258:664-667.
**47)** Finkelstein E: Nifedipine for **radiation** oesophagitis (Letter). Lancet 1986; 1:1205-1206.
**48)** Friedberg W, Faulkner DN, & Synder L: Galactic cosmic **radiation** exposure and associated health risks for air carrier crewmembers. Aviat Space Environ Med 1989; 1104-1108.
**49)** Fry RJ, Grosovsky A, & Hanawalt PC: The inpact of biology on risk assessment -- workshop of the National Research Council's Board on **Radiation** Effects Research. July 21-22, 1997, National Academy of Sciences, Washington, DC. Radiat Res 1998; 150:695-705.
**50)** Gains M: **Radiation** exposure. Practitioner 1989; 233:1631-1634.
**51)** Gardner MJ: Childhood cancer and nuclear installations. Public Health 1991; 105:277-285.
**52)** Geeze DS: Pregnancy and in-flight cosmic **radiation**. Aviat Space Environ Med 1998; 69:1061-1064.
**53)** Gibson PG, Bryant DH, & Morgan GW: **Radiation**-induced lung injury: A hypersensitivity pneumonitis?. Ann Intern Med 1988; 109:288-291.
**54)** Goldsmith JR, Merkin L, & Quastel MR: Evaluation of the **radiation** exposures of Chernobyl "liquidators": Exploratory studies of a sample of immigrants to Israel. Internat J Occup Environ Health 1997; 3:51-59.
**55)** Gottlober P, Bezold G, & Weber L: The **radiation** accident in Georgia: clinical appearance and diagnosis of cutaneous **radiation** syndrome. J Am Acad Dermatol 2000; 42:453-458.
**56)** Grayson JK: **Radiation** exposure, socioeconomic status, and brain tumor risk in the US Air Force: a nested case-control study. Am J Epidemiol 1996; 143:480-486.
**57)** Green LM, Dodds L, & Miller AB: Risk of congenital anomalies in children of parents occupationally exposed to low level ionsing **radiation**. Occup Environ Med 1997; 54:629-635.
**58)** Gribbin MA, Weeks JL, & Howe GR: Cancer mortality (1956-1985) among male employees of Atomic Energy of Canada limited with respect to occupational exposure to external low-linear-energy-transfer ionizing **radiation**. Radiat Res 1993; 133:375-380.

**59)** Grollino MG, Eleuteri P, & Mark HF: Children exposed to chronic contamination after the Chernobyl accident: cytogenetic and radiotoxicological analyses. Arch Environ Med 1998; 53:344-346.
**60)** Grossman CM, Nussbaum RH, & Nussbaum FD: Cancers among residents downwind of the Hanford, Washington, plutonium production site. Arch Environ Health 2003; 58:267-274.
**61)** Gundestrup M & Storm HH: **Radiation**-induced acute myeloid leukaemia and other cancers in commercial jet cockpit crew: a population-based cohort study. Lancet 1999; 354:2029-2031.
**62)** Hagelstrom AH, Gorla NB, & Larripa IB: Chromosomal damage in workers occupationally exposed to chronic low level ionizing **radiation**. Toxicol Lett 1995; 76:113-117.
**63)** Hamilton TE, van Belle G, & LoGerfo JP: Thyroid neoplasia in Marshall Islanders exposed to nuclear fallout. JAMA 1987; 258:629-636.
**64)** Hong JH, Chiang CS, & Campbell IL: Induction of acute phase gene expression by brain irradiation. Internat J Radiat Oncol Biol Phys 1995; 33:619-626.
**65)** Howe GR & McLaughlin J: Breast cancer mortality between 1950 and 1987 after exposure to fractionated moderate-dose-rate ionizing **radiation** in the Canadian fluoroscopy cohort study and a comparison with breast cancer mortality in the atomic bomb survivors study. Radiat Res 1996; 145:694-707.
**66)** ICRP: The principles and general procedures for handling emergency and accidental exposure of workers: A report of the Commitee 4 of the International Commission on Radiologic Protection, in **Radiation** Protection, ICRP Publication 28. International Commission on Radiologic Protection, 1977.
**67)** ILO: Encyclopaedia of Occupational Health and Safety, 3rd ed, 1-2, International Labour Organization, Geneva, Switzerland, 1983.
**68)** Ikenoue T, Ikeda T, & Ibara S: Effects of environmental factors on perinatal outcome: Neurological development in cases of intrauterine growth retardation and school performance of children perinatally exposed to ionizing **radiation**. Environ Health Perspect 1993; 101:53-57.
**69)** Imamura N & Kimura A: Neutropenia among survivors of atomic bomb explosion (letter). Lancet 2000; 355:117.
**70)** Jarrett D: Medical Management of Radiological Casualties Handbook, 1st edition, Armed Forces Radiobiology Research Institute, Bethesda, MD, 1999.
**71)** Joksic G & Spasojevic-Tisma V: Chromosome analysis of lymphocytes from **radiation** workers in tritium-applying industry. Internat Arch Occup Environ Health 1998; 71:213-220.
**72)** Karagas MR, McDonald JA, & Greenberg ER: Risk of basal cell and squamous cell skin cancers after ionizing **radiation** therapy. J Natl Cancer Inst 1996; 88:1848-1853.
**73)** Kasuba V, Rozgaj R, & Sentija K: Chromosomal aberrations in medical staff occupationally exposed to X-rays: a follow-up study. Arh Hig Rada Toksikol 1998; 49:1-8.
**74)** Katayama S, Shimaoka K, & Osman G: **Radiation**-associated thyrotoxicosis. J Surg Oncol 1986; 33:84-87.
**75)** Kauppinen T, Partanen T, & Degerth R: Pancreatic cancer and occupational exposures. Epidemiol 1995; 6:498-502.
**76)** Kendall GM, Muirhead CR, & MacGibbon BH: Mortality and occupational exposure to **radiation**: first analysis of the National Registry for **Radiation** Workers. Br Med J 1992; 304:220-225.
**77)** Kerber RA, Till JE, & Simon SL: A cohort study of thyroid disease in relation to fallout from nuclear weapons testing. JAMA 1993; 270:2076-2082.
**78)** Khokhryakov VF, Belyacv AP, Kudryavtseva TI, et al: Successful DTPA therapy in the case of 239Pu penetration via injured skin exposed to nitric acid. Rad Protect Dosimetry 2003; 105:499-502.
**79)** Lahat E, Goldman M, & Barr J: Comparison of intranasal midazolam with intravenous diazepam for treating febrile seizures in children: prospective randomized study. BMJ 2000; 321:83-86.
**80)** Landtblom A-M, Flodin U, & Karlsson M: Multiple sclerosis and exposure to solvents, ionizing **radiation** and animals. Scand J Work Environ Health 1993; 19:399-404.
**81)** Leonard RB & Ricks RC: Emergency department **radiation** accident protocol. Ann Emerg Med 1980; 9:462-470.
**82)** Lieberman AN, Randarenko IG, & Pethkurov AV: Influence of small doses of ionising **radiation** on the course and result of pregnancies (Russian), in: Polonskaja EJ (Ed), **Radiation** Hygiene, Russian Ministry of Health, Scientific Research Institute for **Radiation** Hygiene, Leningrad, Russia, 1990, pp 100.
**83)** Lincoln TA: Importance of initial management of persons internally contaminated with radionuclides. J Am Ind Hyg Assoc 1976; 37:16-21.
**84)** Lindholm C, Tekkel M, & Veidebaum T: Persistence of translocations after accidental exposure to ionizing **radiation**. Internat J Radiat Biol 1998; 74:565-571.
**85)** Linet MS, Freedman DM, Mohan AK, et al: Incidence of haematopoietic malignancies in US radiologic technologists. Occup Environ Med 2005; 62(12):861-867.
**86)** Little JB: Cellular, molecular, and carcinogenic effects of **radiation**. Hematol/Oncol Clin N Amer 1993; 7:337-352.
**87)** Little MP, De Vathaire F, & Charles MW: Variations with time and age in the risks of solid cancer incidence after **radiation** exposure in childhood. Stat Med 1998; 30:1341-1355.
**88)** Lloyd DC, Edwards AA, & Fitzsimmons EJ: Death of a classified worker probably caused by overexposure to **radiation**. Occup Environ Med 1994; 51:713-718.
**89)** Mangano JJ: A post-Chernobyl rise in thyroid cancer in Connecticut, USA. Eur J Cancer Prev 1996; 5:75-81.
**90)** Manno EM: New management strategies in the treatment of status epilepticus. Mayo Clin Proc 2003; 78(4):508-518.
**91)** Mendelsohn ML: Health Phys 1990; 59:23-28.
**92)** Messiha FS: Developmental toxicity of cesium in the mouse (minireview). Gen Pharmac 1994; 25:395-400.
**93)** Mettler FA Jr, Monsein L, & Davis M: Three-phase radionuclide bone scanning in evaluation of local **radiation** injury: a case report. Clin Nucl Med 1987; 12:805-808.
**94)** Miller RW: Heath Phys 1990; 59:57-61.
**95)** Milroy WC: Management of irradiated and contaminated casualty victims. Emerg Med Clin North Am 1984; 2:667-686.
**96)** Mole RH: Br J Radiol 1987; 60:17-31.
**97)** Mole RH: Radiol Protect Bull 1985; 67:18.
**98)** Mole RH: The effect of prenatal **radiation** exposure on the developing human brain. Interat J Radiat Biol 1990; 57:647-663.
**99)** Movsas B, Raffin TA, & Epstein AH: Pulmonary **radiation** injury (review). Chest 1997; 111:1061-1076.
**100** NATO : NATO/CCMSNACC Pilot Study: Cross-border environmental problems emanating from defence-related installations and activities. Summary final report. Phase 1 1993-1995; Report No. 206. North Atlantic Treaty Organization from Estonia and NATO. Islandi väljak, Estonia. 1995. Available from URL: http://www.vm.ee/nato/ccms/s00/phase1/final/finalsum.html. As accessed (cited 7/30/98).
**101** NCRP: Review of NCRP **Radiation** Dose Limit for Embryo and Fetus in Occupationally Exposed Women, National Council on **Radiation** Protection and Measurements, Washington, DC, 1977.
**102** Nagataki S, Shibata Y, & Inoue S: Thyroid diseases among atomic bomb survivors in Nagasaki. JAMA 1994; 272:364-370.

**103** Natl Acad Sci: The treatment of **Radiation** Injury: Report of Committee on Pathologic Effects of Atomic **Radiation**, Publication 1134, National Academy of Sciences -- National Research Council, Washington, DC, 1963.
**104** Nitta Y, Kamiya K, & Yokoro K: Carcinogenic effect of in utero CF-252 and CO-60 irradiation in C57Bl/6NXC3H/HEf1 (B6C3f1) mice. J Radiat Res 1992; 33:319-333.
**105** Norton S: Toxicol Appl Pharmacol 1986; 83:240-249.
**106** Okada S: A Review of Thirty Years Study of Hiroshima and Nagasaki Atomic Bomb Survivors. J Radiat Res 1975; 16 (Suppl).
**107** Otake & Schull J: Br J Radiol 1984; 57:409.
**108** Otake M & Schull WJ: **Radiation**-related brain damage and growth retardation among the prenatally exposed atomic bomb survivors. Internat J Radiat Biol 1998; 74:159-171.
**109** Pacini F, Vorontsova T, & Molinaro E: Prevalence of thyroid autoantibodies in children and adolescents from Belarus exposed to the Chernobyl radioactive fallout. Lancet 1998; 352:763-766.
**110** Padovani L, Caporossi D, & Tedeschi B: Cytogenetic study in lymphocytes from children exposed to ionizing **radiation** after the Chernobyl accident. Mutat Res 1993; 319:55-60.
**111** Paul ME: Physical agents in the workplace. Seminars in Perinatology 1993; 17:5-17.
**112** Paz-y-Mino C, Leone PE, & Chavez G: Follow up study of chromosomal aberrations in lymphocytes in hospital workers occupationally exposed to low levels of ionizing **radiation**. Mutat Res 1995; 335:245-241.
**113** Peter RU, Braunfalco O, & Birioukov A: Chronic cutaneous damage after accidental exposure to ionizing **radiation**: the Chernobyl experience. J Am Acad Dermatol 1994; 30:719-723.
**114** Pinkerton LE, Bloom TF, Hein MJ, et al: Mortality among a cohort of uranium mill workers: an update. Occup Environ Med 2004; 61:57-64.
**115** Product Information: Ca-DTPA, Trisodium calcium diethylenetriaminepentaacetate. Distributed by: Oak Ridge Associated Universities (www.orau.gov), Oak Ridge, TN, USA, 2003.
**116** Product Information: Radiogardase(TM), Insoluble Prussian blue capsules. Haupt Pharma Berlin GmbH, Berlin, Germany, 2003.
**117** Product Information: Zn-DTPA, Trisodium zinc diethylenetriaminepentaacetate. Distributed by: Oak Ridge Associated Universities (www.orau.gov), Oak Ridge , TN, USA, 2003.
**118** Product Information: lorazepam injection, lorazepam injection. Bedford Laboratories, Bedford, OH, 2004.
**119** REPROTOX : REPROTOX Information System, Scialli AR (Ed), (CD-ROM Version). Georgetown University Medical Center and Reproductive Toxicology Center, Columbia Hospital for Women Medical Center. Washington, DC (Internet Version). Edition expires 1999; provided by Thomson Healthcare Inc., Greenwood Village, CO.
**120** Ramsay CN, Ellis PM, & Zealley H: Down's syndrome in the Lothian region of Scotland -- 1978 to 1989. Biomed Pharmacother 1991; 45:267-272.
**121** Rericha V, Kulich M, Rericha R, et al: Incidence of leukemia, lymphoma, and multiple myeloma in Czech uranium miners: a case-cohort study. Environ Health Perspect 2006; 114(6):818-822.
**122** Roed KH & Jacobsen M: Chromosome aberrations in Norwegian reindeer following the Chernobyl accident. Mutat Res 1995; 346:159-165.
**123** Roman E, Doyle P, & Maconochie N: Cancer in children of nuclear industry employees: report on children aged under 25 years from nuclear industry family study. Br Med J 1999; 318:1443-1450.
**124** Romano E, Ferrucci L, & Nicolai F: Increase of chromosomal aberrations induced by ionising **radiation** in peripheral blood lymphocytes of civil avaition pilots and crew members. Mutat Res 1997; 377:89-93.
**125** Ron E, Ikeda T, Preston DL, et al: Male breast cancer incidence among atomic bomb survivors. J Natl Cancer Inst 2005; 97(8):603-605.
**126** Saddi V, Curry J, & Nohturfft A: Increased hprt mutant frequencies in Brazilian children accidentally exposed to ionizing **radiation**. Environ Mol Mutagen 1996; 28:267-275.
**127** Saenger EL: **Radiation** accidents. Am J Roentgenol 1960; 84:715-728.
**128** Saku T, Hayashi Y, & Takahara O: Salivary gland tumors among atomic bomb survivors, 1950-1987. Cancer 1997; 79:1465-1475.
**129** Salovsky P, Shopova V, & Dancheva V: Pneumonotoxic effects of radioactive dust (RD) from a nuclear power plant in Kozloduy, Bulgaria. Am J Ind Med 2000; 38:639-643.
**130** Sasaki MS, Takatsuji T, & Ejima Y: The F value cannot be ruled out as a chromosomal fingerprint of **radiation** quality. Radiat Res 1998; 150:253-258.
**131** Satoh C, Takahashi N, & Asakawa J: Genetic analysis of children of atomic bomb survivors. Environ Health Perspect 1996; 104(Suppl 3):511-519.
**132** Schneider G & Burkart W: Health risks of ionizing **radiation** (German). Radiologe 1998; 38:719-725.
**133** Scott R, Besag FMC, & Neville BGR: Buccal midazolam and rectal diazepam for treatment of prolonged seizures in childhood and adolescence: a randomized trial. Lancet 1999; 353:623-626.
**134** Servomaa K, Kiuru A, & Grenman R: p53 mutations associated with increased sensitivity to ionizing **radiation** in human head and neck cancer cell lines. Cell Prolif 1996; 29:219-230.
**135** Shanahan EM, Peterson D, & Roxby D: Mutation rates at the glycophorin A and hprt loci in uranium miners exposed to radon progeny. Occup Environ Med 1996; 53:439-444.
**136** Shintani T, Hayakawa N, & Kamada N: High incidence of meningioma in survivors of Hiroshima (Letter). Lancet 1997; 349:1369.
**137** Smith MB, Xue H, & Takahashi H: Iodine-131 thyroid ablation in female children and adolescents -- long-term risk of infertility and birth defects. Ann Surg Oncol 1994; 1:128-131.
**138** Sorahan T & Roberts PJ: Childhood cancer and paternal exposure to ionizing **radiation**: Preliminary findings from the Oxford survey of childhood cancers. Am J Ind Med 1993; 23:343-354.
**139** Sorahan T, Lancashire RJ, & Temperton DH: Childhood cancer and paternal exposure to ionizing **radiation**: A second report from the Oxford survey of childhood cancers. Am J Ind Med 1995; 28:71-78.
**140** Sperling K, Pelz J, & Wegner RD: Frequency of trisomy 21 in Germany before and after the Chernobyl accident. Biomed Pharmacother 1991; 45:255-262.
**141** Stayner LT et al: NIOSH Report 1184B. National Institute for Occupational Safety and Health, 1983.
**142** Streffer C, Muller WU, & Kryscio A: Micronuclei-biological indicator for retrospective dosimetry after exposure to ionizing **radiation**. Mutat Res 1998; 404:101-105.
**143** Thompson LH & Jeggo PA: Nomenclature of human genes involved in ionizing **radiation** sensitivity. Mutat Res 1995; 337:131-134.
**144** Tomei F, Papaleo B, & Fantini S: Vascular effects of occupational exposure to low-dose ionizing **radiation**. Am J Ind Med 1996; 30:72-77.
**145** Toohey RE: Internal dose assessment in **radiation** accidents. Rad Protect Dosimetry 2003; 105:329-331.
**146** Tucker JD, Ramsey MJ, & Lee DA: Validation of chromosome painting as a biodosimeter in human peripheral lymphocytes following acute exposure to ionizing **radiation** invitro. Internat J Radiat Biol 1993; 64:27-37.
**147** Tucker JD, Tawn EJ, & Holdsworth D: Biological dosimetry of **radiation** workers at the Sellafield nurlear facility. Radiat Res 1997;

148:216-226.
**148** Vanagunas A, Jacob P, & Olinger E: **Radiation**-induced esophageal injury: A spectrum from esophagitis to cancer. Am J Gastroenterol 1990; 85:808-812.
**149** Verger P: Down syndrome and ionizing **radiation**. Health Physics 1997; 73:882-893.
**150** Verzijl JM, Joore JCA, & van Dijk A: In vitro binding characteristics for cesium of two qualities of prussian blue, activated charcoal and resonium-a. Clin Toxicol 1992; 30:215-222.
**151** Verzijl JM, Lie RL & Savelkoul TJ et al: In-vitro binding characteristics for cesium of two qualities of Prussian blue, activated charcoal, and Resonium-A(R). Personal Communication, 1990.
**152** Voelz GL: Current approaches to the management of internally contaminated persons, in: Hubner KF & Fry SA (Eds), The Medical Basis for **Radiation** Accident Preparedness, Elsevier, New York, NY, 1980, pp 311-325.
**153** WHO: Radiologic Aspects, in: Guidelines for drinking-water quality, 2nd ed, World Health Organization, Geneva, Switzerland, 1993, pp 114-121.
**154** Wagner RH, Boles MA, & Henkin RE: Treatment of **radiation** exposure and contamination. Radiographics 1994; 14:387-396.
**155** Wakeford R & Berry RJ: Nuclear facilities and cancers. Ann Acad Med Singapore 1996; 25:468-476.
**156** Wakeford R: The risk of childhood cancer from intrauterine and preconceptional exposure to ionizing **radiation**. Environ Health Perspect 1995; 103:1018-1025.
**157** Weinberg AD, Kripalani S, & McCarthy PL: Caring for survivors of the Chernobyl disaster. What the clinician should know. JAMA 1995; 274:408-412.
**158** Wiggs LD, Johnson ER, & Cox-DeVore CA: Mortality through 1990 among white male workers at the Los Alamos National Laboratory: Considering exposures to plutonium and external ionizing **radiation**. Health Physics 1994; 67:577-588.
**159** Wilson VL, Taffe BG, & Shields PG: Detection and quantification of 8-hydroxydeoxyguanosine adducts in peripheral blood of people exposed to ionizing **radiation**. Environ Health Perspect 1993; 99261-99263.
**160** Wing S & Richardson DB: Age at exposure to ionising **radiation** and cancer mortality among Hanford workers: follow up through 1994. Occup Environ Med 2005; 62(7):465-472.
**161** Wing S, Richardson D, Wolf S, et al: Plutonium-related work and cause-specific mortality at the United States Department of Energy Hanford Site. Am J Ind Med 2004; 45(2):153-164.
**162** Wones R, Radack K, & Martin V: Do persons living near a uranium processing site have evidence of increased somatic cell gene mutations -- a first study. Mutat Res 1995; 335:171-184.
**163** Yoshimaru H, Otake M, & Schull WJ: Further observations on abnormal brain development caused by prenatal A-bomb exposure to ionizing **radiation**. Internat J Radiat Biol 1995; 67:359-371.
**164** Zolzer F, Hillebrandt S, & Streffer C: **Radiation** induced G(1)-block and p53 status in six human cell lines. Radiother Oncol 1995; 37:20-28.
**165** Zwingmann IN, Welle IJ, & van Herwijnen M: Oxidative DNA damage and cytogenetic effects in flight engineers exposed to cosmic **radiation**. Environ Mol Mutagen 1998; 32:121-129.