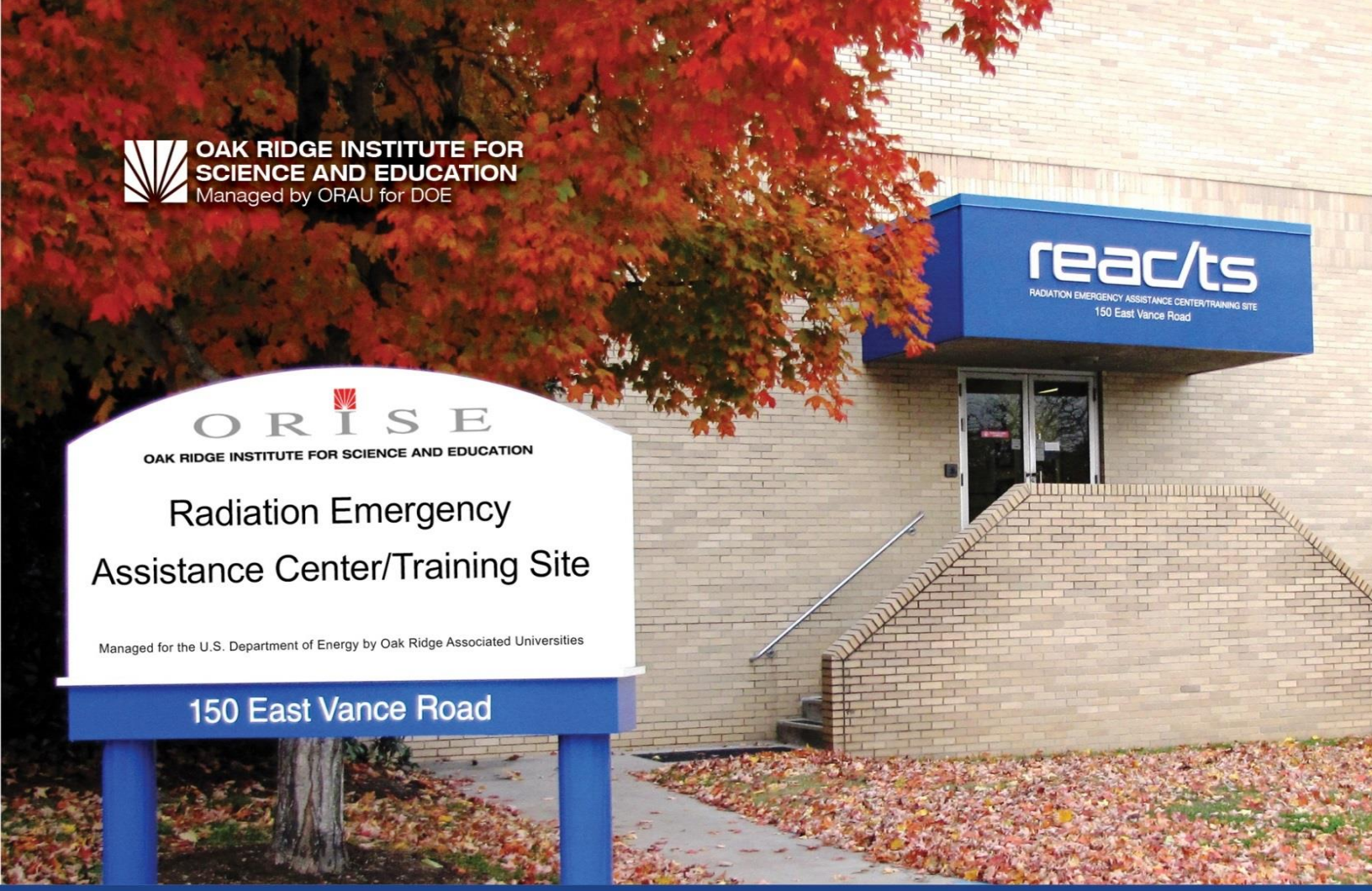



REAC/TS

Radiation Emergency Assistance Center/Training Site

Managed by ORAU for DOE

# The Medical Aspects of Radiation Incidents

4th Edition

PO Box 117, MS-39 • Oak Ridge, TN 37831
Office: (865) 576-3131 • 24-hr Number: (865) 576-1005
www.orise.orau.gov/reacts

The **Radiation Emergency Assistance Center/Training Site (REAC/TS**) has provided the Department of Energy with expertise related to the medical management of radiation incidents since 1976. REAC/TS maintains a 24/7 national and international radiation emergency response capability that includes a staff of physicians, nurse/paramedics, and health physicists experienced in treatment of radiation injuries/illnesses, radiation dose evaluations, and decontamination. The **REAC/TS Cytogenetic Biodosimetry Lab (CBL**) has the capability to perform dicentric and other chromosomal analyses for radiation biodosimetric purposes. REAC/TS also maintains a radiation accident registry and a DTPA/Prussian Blue registry for the Department of Energy. Additionally, REAC/TS provides continuing medical education in its field of expertise through regularly scheduled in-house courses and specially designed off-site courses.

REAC/TS is a radiation emergency medical response asset of the U.S. Department of Energy/National Nuclear Security Administration (DOE/NNSA). **REAC/TS provides treatment capabilities and consultation assistance on a 24-hour basis, and can be reached by calling 865-576-3131 (weekdays) or, after normal business hours, via the DOE Oak Ridge Operations Center at 865-576-1005.**

The **Oak Ridge Institute for Science and Education (ORISE)** is a U.S. Department of Energy institute focusing on scientific initiatives to research health risks from occupational hazards, assess environmental cleanup, respond to radiation medical emergencies, support national security and emergency preparedness, and educate the next generation of scientists. ORISE is managed by Oak Ridge Associated Universities.

This document was produced under contract number DE-SC0014664 between the U.S. Department of Energy and Oak Ridge Associated Universities by Stephen L. Sugarman, MS, CHP; Wayne Baxter, RN, EMT-P; Angie Bowen, RN, NRP;. A. Seaton Garrett, MD; Ronald E Goans, MD, PhD; Mark Jenkins, PhD, CSP; Carol Iddins, MD; Gordon K. Livingston, PhD; Adayabalam Balajee, PhD; and Nicholas Dainiak, MD, FACP.

Special thanks to the City of Oak Ridge Fire Department and Paramedic Austin Keathley for his assistance with the decontamination demonstration pictures.

# THE MEDICAL ASPECTS OF RADIATION INCIDENTS

Radiation Emergency Assistance Center/Training Site
REAC/TS
PO Box 117, MS-39
Oak Ridge, TN 37831
Office: (865)576-3131
24-hour Number: (865)576-1005
www.orise.orau.gov/reacts

## Contents

# Section 1 – Introduction and Radiation Basics

Medical care providers are expected to deliver care to patients because of a multitude of scenarios. One of those scenarios involves the patient who has been exposed to and/or contaminated with radioactive materials. This document is intended to provide basic information to physicians and other healthcare professionals necessary for the proper medical management of these individuals.

The most important consideration in the medical evaluation of people involved in a radiation incident is the medical stability of the affected individuals. The relative magnitude of the situation and the resources needed to address the emergency are also important considerations.

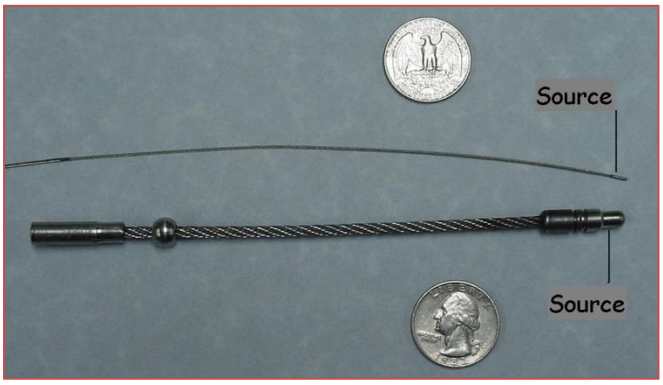
> **Small-scale** incidents are those occurring in laboratories, hospitals, nuclear power plants, etc., involving small amounts of radioactive materials with the potential exposure and/or contamination of one or a few individuals.
> **Large-scale** incidents are those involving relatively large quantities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

High-level acute external doses of ionizing radiation typically pose the greatest danger to people. Low-levels of internal or external contamination with radioactive material generally pose little risk. As with all emergency response situations, safety of the responder is a primary concern. A site known to be radiologically contaminated should be assessed before general entry and responders should be advised to limit their time in high dose-rate areas. There is minimal risk typically associated with handling a radiologically-contaminated casualty. See Section 6 for guidance related to decontamination techniques.

The National Council on Radiation Protection Report No. 138 (2001), Management of Terrorist Events Involving Radioactive Material, discusses various incidents by which personnel could be exposed to radiation or contaminated with radioactive materials. NCRP Report No. 165 (2010), Responding to Radiological or Nuclear Terrorism: A Guide for Decision Makers, may also be of interest. Below are generally accepted categorizations of some of the varying radiological terrorist threats.

- **Radiation Exposure Device (RED)**: radioactive material, in a sealed source or within a container, and intended to expose people in the vicinity of the device to a high-level external dose. Some materials used in commercial equipment contain radioactive sources that could function as an RED. Industrial radiography sources

(as pictured above, lower item) are found in the civilian sector and could be used as a RED. Brachytherapy sources (as pictured above, top item) are also common.




- **Radiological Dispersal Device (RDD)**: any device that causes intentional dissemination of radioactive material without a nuclear detonation. An RDD can cause internal dose through inhalation or ingestion of released radioactive material and external dose because of surface contamination. An RDD intended to disperse radioactive material by use of an explosive device would likely result in injuries associated with blasts and heat to become contaminated with radioactive material. Additionally, the contaminated environs would likely complicate medical response and/or evacuation.
- **Improvised Nuclear Device (IND)**: defined as a device designed by terrorists to produce a nuclear detonation. At full or partial yield, an IND is physically the same thing as a nuclear weapon: blast, burns, and radiation are the forms of energy and are also the cause of injury. An IND exposes people to trauma, high-level external dose, inhalation and ingestion of radioactive materials, and skin contamination. Should an IND fail to detonate properly, the high explosives may disseminate the nuclear material around the environment, thus effectively becoming an RDD.

**Planning**

The U.S. Environmental Protection Agency has established RECOMMENDATIONS for mission-specific risk-based dose limits that include life-saving activities. This guidance can be found in EPA-400/R-17/001, PAG Manual: Protective Action Guides and Planning Guidance for Radiological Incidents (Jan, 2017). The manual states that workers may receive up to 10 rem (0.1 Sv) to protect valuable property and up to 25 rem (0.25 Sv) for saving a life. They also state that greater than 25 rem (0.25 Sv) can be received for lifesaving if the responders volunteer, are non-pregnant adults, and are fully aware of the risks involved. These emergency doses are for a once-in-a-lifetime exposure and are not added to occupational dose. ICRP Publication 103 recommends no dose restrictions for lifesaving if the benefit to others outweighs the rescuer's risk (informed volunteers). For other *urgent* rescue operations, upper dose recommendations are 1000 mSv (100 rem) or less. Other rescue operations have recommended limits of less than 100 mSv (10 rem).

Operations in some radiological areas could result in personnel receiving sufficient radiation dose or radioactive contamination to warrant medical evaluation and

decontamination. Significant amounts of radioactive material may be deposited on surfaces after the detonation of a nuclear weapon, use of a RDD, or a nuclear plant accident.

In addition to the above, personnel can be exposed to radiation and/or become contaminated from accidents involving storage or transportation of radioactive materials, use of industrial sources, or during the course of performance of routine functions throughout the nuclear industry.

## Types of Radiation

The five types of radiation of primary importance:


- **Alpha (α) particles**: charged particles made up of two protons and two neutrons emitted from heavy nuclei including U, Pu, and Am. Alpha particles cannot travel far (about an inch in air) and penetrate no more than a few μm in skin (basically, the dead layer of the skin). Thin clothing, or even a sheet of notebook paper, is an effective shield for alpha particles. Radionuclides that emit alpha particles are therefore a negligible external hazard but can be important in an inhalation or ingestion incident. Due principally to their relatively large size and charge, alpha particles are efficient at creating ionization, thus increasing the potential for biological damage. Therefore, regulatory limits on intakes of radioisotopes emitting alpha particles are typically much more restrictive than for other radiation types.
- **Beta (β) particles**: electrons emitted from the nuclei of isotopes such as tritium and $^{90}$Sr. Beta particles can travel a short distance in tissue (a few millimeters) and up to a couple of meters in air. Most beta particles can be shielded by a thin layer of plastic. The clear face-piece of a full-face respirator is an effective shield for many beta particles. Large quantities of beta-emitting radioactive materials deposited on the skin can damage the basal layer of the epidermis, or deeper, and cause what are commonly referred to as radiation burns. Beta-emitters are also important if inhaled or ingested.
- **Gamma (γ) rays**: non-particulate electromagnetic radiation (with wavelengths shorter than UV) capable of creating ionization that are emitted from various radioisotopes. Gamma rays originate in the nucleus. They are highly energetic and can pass through matter easily, indicating that they are not very efficient at creating ionization (compared to alpha particles, for instance). Regulatory limits on intakes of gamma-emitting radionuclides are typically much less restrictive than those of alpha-emitting radionuclides. Because of its high penetrability, gamma radiation can result in exposure to the internal organs from external sources, resulting in

damage to them, and are thusly a concern for external irradiation. Dense materials such as lead are used to shield gamma rays.

- **X-rays**: different from gamma rays only in their point of origin: outside of the nucleus as opposed to within it.
- **Neutrons**: uncharged particles, important because they are emitted during the fission process and in some nondestructive testing procedures. They are not as commonly encountered as the other four types of radiation discussed. Neutrons can have from 3 to 20 times more risk of future effects associated with them than gamma rays. Neutrons are the only type of the five discussed that have the ability to make something else radioactive (neutron activation).

## Means of Exposure

An individual may receive radiation dose from an external source, by loose radioactive material deposited on the skin or equipment, or by ingesting or inhaling radiological particulates. Ingestion or inhalation of radioactive material may cause internal dose to the whole body or to a specific organ over a period of time, but dose levels received in this manner have historically not normally been acutely lethal.

## Irradiation vs. Contamination

A person is irradiated when they are "exposed" to ionizing radiation in much the same way a person is "exposed" to light when someone shines a flashlight on them. In the case of irradiation, there is no material transferred. This means that an irradiated patient has no radioactive material on them and poses no radiological hazard to the treatment team.

When people have radioactive materials on/in them, they are said to be contaminated. Note that a person is not contaminated with alpha particles, for instance, but with materials such as $^{241}Am$ that emit alpha particles. A good way to think of this is to imagine a sealed container of radioactive baby powder (This one emits gamma rays!). One can hold the container and be exposed to the gamma rays penetrating through the walls of the container without getting the baby powder on his hands. Should a leak develop around the lid, allowing some of the material to escape, the person may have the powder on his hands, thus resulting in contamination.

Controlling radioactive contamination is very similar to controlling loose baby powder. A common sense approach should be taken to limit the spread of the material. This is usually done by proper utilization of protective clothing, controlling

entry and exit to/from a contaminated area, minimizing the amount of material dispersed into the air, and proper personnel monitoring. There are other methods one can employ to control the spread of contamination (use of negative pressure, avoid actions that may re-suspend the material, covering or removing unnecessary items from the area, etc.) but, typically, contamination control is a process that, although important, needn't be overly complicated.

## Units

The basic unit of radioactivity used in the U.S. is the curie (Ci) and is defined as 3.7 x $10^{10}$ becquerels (Bq). The becquerel, one disintegration per second, is the basic SI unit (from the French *le Système International d'unités*). One Ci is equal to 37 gigabecquerels (GBq) and one GBq is equal to 27 millicuries (mCi). Activity is the concept used to quantify the amount of radioactive material present. Conventional units such as ounces, grams, etc. should not be used to quantify the amount of radioactive material present. For instance, one gram of cobalt-60 is a little over 1,100 Ci (~40,000 GBq) while one gram of uranium-235 is about 2.1 μCi (~ 78 kBq).

Some useful activity conversions are
Where:
G = giga (1 x $10^{9}$), M = mega (1 X $10^{6}$), k = kilo (1 x $10^{3}$)
m = milli (1 x $10^{-3}$), μ = micro (1 x $10^{-6}$), n = nano (1 x $10^{-9}$)

**Table 1 – Activity Conversions**

| | | | |
|---|---|---|---|
| 1 terabecquerel | 1 TBq | 27 curies | 5.99E13 dpm |
| 1 gigabecquerel | 1 GBq | 27 millicuries | 5.99E10 dpm |
| 1 megabecquerel | 1 MBq | 27 microcuries | 5.99E7 dpm |
| 1 kilobecquerel | 1 kBq | 27 nanocuries | 5.99E4 dpm |
| 1 becquerel | 1 Bq | 27 picocuries | 5.99E1 dpm |
| 1 kilocurie | 1 kCi | 37 terabecquerels | 2.22E15 dpm |
| 1 curie | 1 Ci | 37 gigabecquerels | 2.22E12 dpm |
| 1 millicurie | 1 mCi | 37 megabecquerels | 2.22E9 dpm |
| 1 microcurie | 1 μCi | 37 kilobecquerels | 2.22E6 dpm |
| 1 nanocurie | 1 nCi | 37 becquerels | 2.22E3 dpm |

The amount of time it takes for the activity to decrease to ½ of its original value is called the half-life. Half-life cannot be altered by outside forces.

Exposure relates to the potential to create ionization in air. The units are the roentgen (R) in the U.S. and coulombs per kilogram in SI units. These units are for "ionization in air," so they are not extremely useful when applied to the medical management of

radiation incident victims. Once energy is deposited into tissue it is known as absorbed dose.

Absorbed dose is a measure of the energy deposited in tissue by ionizing radiation. The U.S. unit is the rad. One rad is equal to 100 ergs ($10^{-7}$ joules) of energy deposited into one gram of tissue. The SI unit for absorbed dose is the gray (Gy), which is equal to one joule of energy deposited into one kilogram of tissue. For relating acute medical effects, it is widely considered that the most appropriate unit to use is the rad or Gy since the acute effects (discussed in Sections 3 and 4) are largely driven by the amount of energy deposited into a particular tissue.

1 Gy = 100 rad  1 centigray (cGy) = 1 rad

The differences in the future risk (i.e., risk of future cancer induction, for instance) between the different radiation types are approximated by use of a quality factor (QF, for dose equivalent, used in the U.S.) or a radiation weighting factor ($w_R$, for equivalent dose, used internationally). Another way to think of this is that it is a comparison of a dose of one type of radiation required to produce a given effect to the dose of a different type of radiation required to produce the same effect. The difference in dose equivalent (uses QF) and equivalent dose (uses $w_R$) is found in the definitions used by differing ICRP reports. In simple terms, the QF and $w_R$ represent how much more risk is associated with one radiation type versus the standard (gamma, x-ray where the $w_R$ and QF = 1). The dose in Gy times the $w_R$ yields the equivalent dose, measured in sieverts (Sv). The corresponding U.S. unit for the sievert is the rem. The $w_R$ for x-ray or gamma radiation is one, so for pure gamma radiation:

100 rad x 1 = 100 rem, or 1 Gy x 1 = 1 Sv

The $w_R$ for alpha radiation is 20, so 1 mGy (or 100 mrad) because of alpha radiation is equal to 20 mSv (or 2 rem). Beta radiation has a $w_R$ of one, and for neutrons it lies between three and 20, depending on the neutron energy.

Occupational dose limits, related in rem or Sv, are in place primarily for risk limitation and fall below the normal thresholds associated with acute medical effects. It is sometimes helpful to reference regulatory limits as a comparison point when trying to explain the magnitude of the dose that may have been received by a patient or when in conversations with other interested parties.

**Table 2A - Annual Regulatory Limits (U.S. NRC)**

| | rem | mSv |
|---|---|---|
| **Non-Occupational Limit** | | |
| Members of the public | 0.1 | 1 |
| **Occupational Limits** | | |
| Whole body (internal + external) | 5 | 50 |
| Any individual organ | 50 | 500 |
| Lens of the eye | 15 | 150 |
| Skin | 50 | 500 |
| Extremities | 50 | 500 |
| Fetal dose (declared pregnancy) | 0.5 | 5 |

**Table 2B – ICRP Publication 103 General Recommendations**

| | rem | mSv |
|---|---|---|
| **Non-Occupational Limit** | | |
| Whole body (internal + external) | 0.1 | 1 |
| Lens of the eye | 1.5 | 15 |
| Skin | 5 | 50 |
| **Occupational Limits** | | |
| Whole body (internal + external) | 2 | 20 |
| Any individual organ | n/a | n/a |
| Lens of the eye | 2* | 20* |
| Skin | 50 | 500 |
| Extremities | 50 | 500 |
| Fetal dose (declared pregnancy – remainder of pregnancy) | 0.1 | 1 |

* Recommended by IAEA, 2011

In the US, many radiation detection instruments such as the G-M (Geiger-Mueller) detector or ion chamber use the unit roentgen (R), or a submultiple such as mR. The R is a unit of ionization in air. The ion chamber, for instance, is an air filled detector so the charge generated in the detector by an incoming ionizing event is appropriately measured in roentgens. For gamma radiation, coulombs/kg (R), Gy (rad), and Sv are fairly close to each other. So, even though the units are different, they are often – conversationally – used interchangeably. For beta radiation, a multiplication factor is usually applied when using an ion chamber. Health physicists can help with this.

## Specific Gamma Ray Constant

The *gamma constant* for an isotope is the gamma ray exposure rate in mSv per hour at a one centimeter distance from a one MBq point source (for approximate R/hr/mCi, multiply by 3.7). Three common radioisotopes thought to be of interest to terrorist organizations are $^{192}$Ir, $^{137}$Cs, and $^{60}$Co. Gamma constant information can be found in Section 2, Table 3.

Aside from the medical assessment, two principles are of paramount importance in the medical management of the irradiated patient: *early estimation of the magnitude of the radiation/contamination event and identification of the radioisotope(s) in question*. These principles strongly influence subsequent treatment decisions.

**Incident**

An individual goes into a construction area where a 3.7 TBq (100 Ci) $^{192}$Ir source is lying in the floor. The source, typically used for industrial radiography, was inadvertently left behind by the radiographer. The patient worked 1 m away from the source. He estimated being in the vicinity of the source for 15 minutes. What is his estimated whole-body dose?

**Solution**

An approximate dose from a small source is the gamma constant multiplied by the activity of the source times the amount of time spent near the source – all divided by the square of the person's distance from the source in meters (or cm, as appropriate). The gamma constant for $^{192}$Ir is 1.24 mSv/h at 1 cm from the source per MBq (gamma constants for selected radioisotopes can be found in Table 3).

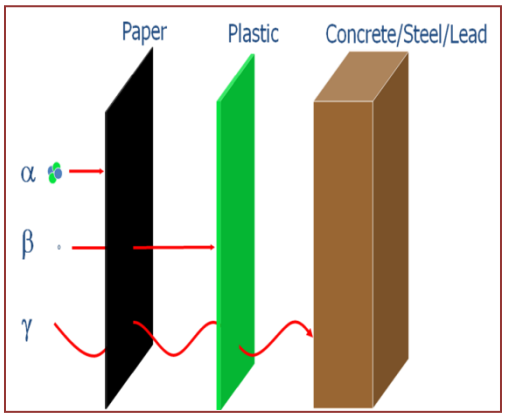
$$\text{Dose} = 1.24\ \text{mSv/hr/MBq} \times 3.7\text{E6 MBq} \times 0.25\text{hr}/(100\text{cm})^2 = \sim 115\ \text{mSv}$$

As discussed in Section 3, this incident should result in no significant acute medical consequence to the patient. Reassurance to the patient would likely be in order regarding medical issues. Although this is a rough approximation, it is adequate given the usual uncertainty with the individual's exact distance from the source and the time spent near it. The dose rate for a point source decreases as the square of the distance, so the dose would be substantially smaller at greater distances from the source. This is called the inverse square law, which essentially says, "If you double the distance, you quarter the dose." It is therefore important to minimize time near a source and maximize distance from it. For example:

At 1 m the dose = ~ 120 mGy (12 rads)
At 2 m the dose = ~ 120 mGy/$2^2$ = 30 mGy (3 rads)
At 3 m the dose = ~ 120 mGy/$3^2$ = about 13 mGy (1.3 rads)

The treating physician and assisting health physicist should maintain open communications to ensure the dose calculations and the anticipated medical signs/symptoms somewhat agree. In the event the medical ramifications do not agree with what was predicted by the dose estimations, time and distance estimates may be at fault. Effort should be made to resolve these types of issues. It is not uncommon for the incident investigation to uncover new facts or for initial recollections of an incident to change as time goes on.

## Personnel Protection




ALARA (As Low As Reasonably Achievable) is the underlying philosophy associated with protecting people from ionizing radiation. It basically means that one should not unnecessarily expose themselves to radiation without the benefit outweighing the risk. Time, distance, and shielding are widely considered to be the primary concerns. At REAC/TS, we like to add a fourth item to the list – quantity. All four of these concepts are used concurrently with the others. For instance, if one were to increase the distance from a radioactive source they are actually adding more shielding (yes, air is a shield). To spend less time in an area one moves farther away from the source (distance, and thusly, shielding). When one minimizes the quantity of radioactive material in an area they are moving the source farther away. As one can see, protecting oneself from ionizing radiation is nothing more than using good common sense: minimize the time around the source, increase the distance from the source, put "stuff" between the target and the source, and/or simply remove the source.

Appropriate personnel dosimetry should be used to monitor external doses to ensure they are maintained ALARA. Dosimeter types include film badges, thermoluminescent dosimeters (TLD), and optically stimulated luminescent dosimeters (OSLD). Additionally, direct read-out dosimeters (DRD) are available. Whereas TLDs, OSLDs, and film badges must be read by special equipment, DRDs allow the user to continually track their accumulated dose. Dosimetry types should be researched and the appropriate type selected for one's individual needs.

Areas of contamination could result not only from industrial or medical sources, but also from the use of an RDD, detonation of a nuclear device, or other reasons. External contamination by radioactive materials can occur when an individual

traverses a contaminated area without appropriate protective clothing. If, for instance, an incident occurs causing the radioactive materials to become airborne or the individual is wounded while in the contaminated area, he/she could possibly become internally contaminated. Radiologically contaminated patients generally pose no danger to healthcare personnel due to irradiation. Medical providers must therefore be prepared to provide prompt treatment of conventional trauma complicated by ionizing radiation or radioactive contamination.

Protective clothing is used to protect the medical provider from external contamination. The purpose of protective clothing is simply to keep the radioactive material off of skin or personal clothing. Paper coveralls, cloth coveralls, and surgical garb, for example, are acceptable forms of protective clothing. Concerns for heat stress should be taken into account since most people are not likely used to working in extra layers of clothing. Medical personnel should be monitored for contamination and, if necessary, decontaminated following treatment and decontamination of contaminated patients.

Standard issue particulate protective masks (respirators) afford excellent protection from inhalation and ingestion of most radioactive material. Since these respiratory protection devices are typically designed to filter particulates, radon and tritium gas will pass through the filters. However, short exposures to these nuclides are not usually medically significant. Keep in mind that surgical masks are not intended for respiratory protection – they are used to protect the patient.

# Section 2 – Initial Medical Response

## Initial Medical Response

Patients should be evaluated and treated based on current triage standards. Lifesaving interventions take priority over contamination concerns (see REAC/TS patient treatment algorithm in Appendix A). The use of universal precautions by healthcare professionals has been shown to mitigate radioactive contamination concerns. A non-contaminated patient who has only been irradiated poses no radiological hazard to the healthcare provider. In order to prepare an effective treatment plan, an early estimation of the dose magnitude is needed. The use of the appropriate gamma constant is a rapid way to estimate the exposure (i.e., dose) at a distance. One needs to know the source activity (A), the isotope and corresponding gamma constant (Γ), the distance the victim was from the source (m or cm), and the time in the area (t). The following formula can be used to determine the dose at a distance. Be sure to keep the units consistent with regard to U.S. units and SI units.

$$\frac{(A)(\Gamma)(t)}{(m)^2}$$

Dose conversion factors are also available to help determine skin doses due to handling a radioactive source when time, radioisotope, and activity are known. Table 3 provides gamma constant information along with doses to the skin at various depths associated with contact with listed radioactive sources. Please note that the contact dose information assumes the radioactive source is encapsulated in stainless steel (thin).

**Table 3 – Dose Conversion Factors**

**Approximate dose rates to the skin for 1 MBq in a sealed source - PHITS Simulations**

| | | *Dose to first 0.07mm* | | | *Dose to first 1mm* | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Nuclide | Gamma Constant (mSv-cm$^2$/ hr-MBq) | Dose Rate Photon Only (mSv/h) | Dose Rate due to secondary electron buildup in encapsulation (mSv/h) | Dose Rate Total (mSv/h) | Dose Rate Photon Only (mSv/h) | Dose Rate due to secondary electron buildup in encapsulation (mSv/h) | Dose Rate Total (mSv/h) | Dose rate at 1cm tissue depth (mSv/h) | Dose rate at 3cm tissue depth (mSv/h) |
| Cs-137 | 0.927 | 0.95 | 3.99 | 4.94 | 2.90 | 1.28 | 4.18 | 0.48 | 0.065 |
| Co-60 | 3.48 | 1.60 | 14.00 | 15.60 | 5.42 | 8.20 | 13.62 | 1.74 | 0.262 |
| Ir-192 | 1.24 | 2.65 | 6.80 | 9.45 | 5.12 | 1.04 | 6.16 | 0.59 | 0.092 |
| Ra-226 | 2.23* | 2.15 | 11.30 | 13.45 | 5.30 | 4.80 | 10.10 | 1.28 | 0.157 |
| Se-75 | 0.548 | 1.95 | 4.61 | 6.56 | 2.43 | 0.47 | 2.90 | 0.21 | 0.022 |

- 0.7 and 1 mm data from *Improved Contact Dose Rate Conversion Factors and Secondary Electron Correction Factors for Encapsulated Gamma Sources*: Presented by Ed Waller on 07/12/17 - Raleigh, NC - Health Physics Society Annual Meeting - Session WAM-A.10 (Primary Author: Eric Heritage, University of Ontario Institute of Technology)
- 1 cm and 3 cm data was provided by Ed Waller on 03/02/2016 via personal correspondence.
- Cs, Co, Ir, Ra 1 cm and 3 cm data closely resembles that published in NCRP 40.
- No data available in NCRP 40 for Se.
- Gamma constant information from *Exposure Rate Constants and Lead Shielding Values for Over 1,100 Radionuclides* (Smith, Stabin – Health Physics – 2012) – converted from conventional US units listed in the reference
- * Converted from NCRP 40 (includes daughter contributions)

**Note: Multiply mSv/hr/MBq by 3.7 to get R/hr/mCi**

Table data compiled by Steve Sugarman

## Major Medical Issues

- Victims of a radiological incident require prompt medical evaluation, diagnosis, and treatment of radiation-related injuries. Healthcare providers are extremely unlikely to receive a medically significant acute radiation dose when providing patient care to casualties with radioactive debris in wounds provided that they observe standard ALARA principles (see page 11). The possibility of contamination should be reviewed as standard operating procedure. Contamination of healthcare providers is unlikely provided they use universal precautions and follow proper contamination control guidelines.
- Clinical signs and symptoms can be used to estimate a radiation dose to a patient (referred to as biological dosimetry).This includes time to emesis and a decline in the lymphocyte count post-irradiation.

- A baseline CBC with differential should be obtained at the time of initial presentation and repeated every 6-8 hours for 48 hours. Lymphocyte depletion follows dose-dependent, first-order kinetics after high-level doses involving penetrating radiations.
- Protracted vomiting within one hour post-irradiation is indicative of a dose in the 6-8 Gy range. For a time to emesis of approximately 2 hours, the effective whole-body dose is likely to be at least 4 Gy. Vomiting at 4 hours post irradiation is indicative of a dose in the 2 Gy range. The absence of vomiting does not preclude a significant exposure.
- Medical management of patients with acute, moderate to severe radiation exposure (effective whole-body dose $\geq$ 2 Gy) should emphasize the rapid administration of colony-stimulating factors (CSF) to enhance hematopoietic recovery. All of these compounds decrease the duration of radiation-induced neutropenia and stimulate neutrophil recovery, albeit with some variability.
- Currently, the only hematopoietic CSFs with FDA approval for management of ARS-associated neutropenia are recombinant forms of granulocyte-colony stimulating factor (G-CSF, Neupogen®) and the pegylated form of G-CSF (Neulasta®). Granulocyte-macrophage-colony stimulating factor (GM-CSF, Leukine®) and other biosimilars are available for use with FDA Emergency Use Authorization (EUA). Recommended dosages are given in Section 3 (ARS).
- Adherence to the current Infectious Diseases Society of America (IDSA) guidelines for high-risk neutropenia is recommended for patients developing febrile radiation-induced neutropenia.
- Indications for the clinical use of cytokines and antimicrobials (antibiotics, antifungals, and antivirals) can be found in a WHO consensus statement published in Disaster Medicine and Public Health Preparedness (October, 2011).

Time to Vomiting may be a useful preliminary indicator available to the whole body dose received by a victim. Vomiting from a radiation dose is persistent and difficult to control. At lower doses, vomiting may not occur, but at higher doses, vomiting approaches 100%.

Recommended Anti-Emetic Dosages

Selective 5-HT3 receptor antagonists are recommended for radiation-induced emesis:

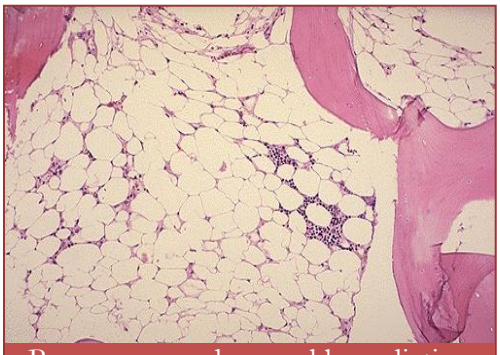
- Ondansetron; Zofran®, Zofran ODT®
- Antidopaminergics (metoclopramide) may also be used.

**Table 4 – Quick Triage Using Time to Vomiting**

| Dose in Gray (Gy) | Time to Vomiting (hours) | % of victims | Survivability LD 50/60 |
|---|---|---|---|
| 0 | 0 | - | |
| 1 | N/A | 19 | |
| 2 | 4.63 | 35 | |
| 3 | 2.62 | 54 | |
| 4 | 1.74 | 72 | With intense treatment |
| 5 | 1.27 | 86 | |
| 6 | 0.99 | 94 | |
| 7 | 0.79 | 98 | |
| 8 | 0.66 | 99 | |
| 9 | 0.56 | 100 | |
| 10 | 0.48 | 100 | |

**Biodosimetry Based on Acute Photon-Equivalent Exposures; Waselenko, JK, "Medical Management of the Acute Radiation Syndrome: Recommendations of the Strategic National Stockpile Radiation Working Group", Ann Intern Med, 2004.**

# Section 3 – Acute Radiation Syndrome


Bone marrow damaged by radiation

Lifesaving care requires preferential attention before radiation and/or contamination concerns. Acute Radiation Syndrome results from external exposure to radiation doses greater than one Gy delivered to the whole body over a short time period (high dose rate). The whole body, in this instance, can be considered to be proximal to the knees and elbows, to include the head. A complete clinical and event history (including locations and activities during the radiological incident, history of present illness and past medical history, and available radiological information) and physical examination should be obtained. The health physicist is a critical resource for much of the history pertaining to the radiological incident.

## Pathophysiology

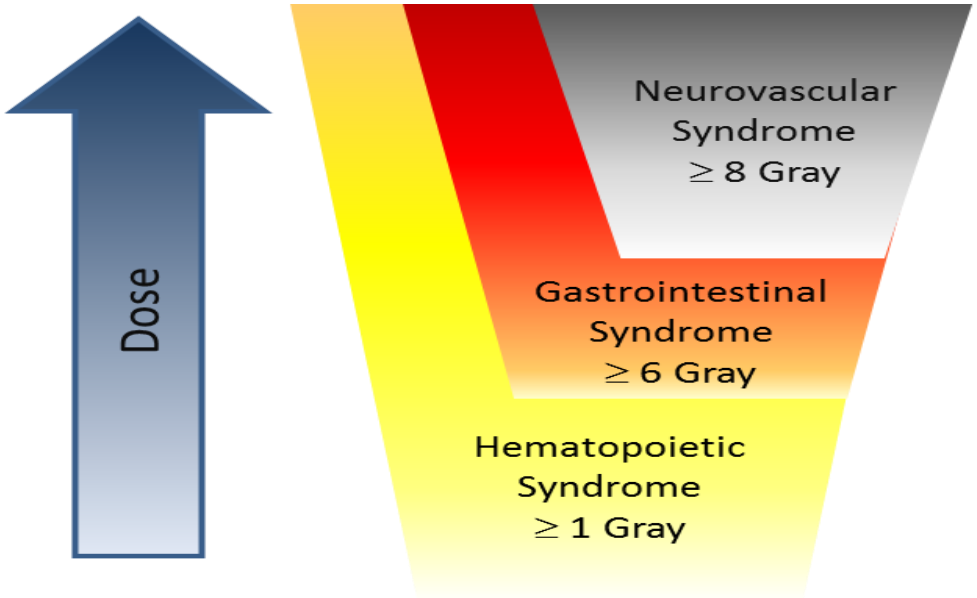
Radiation damage to cells occurs within microseconds of exposure. Cellular damage is generally most severe in rapidly reproducing cell types. Stem cells in the bone marrow, intestinal crypt cells, and the basal layer of skin are particularly susceptible to radiation injury.

## ARS and Dose

The Acute Radiation Syndrome (ARS) is an acute illness that varies in onset from a few hours to weeks. The illness typically follows a pattern of prodromal signs/symptoms, a latent period, and a period of manifest illness, followed by recovery or death. Each phase varies in intensity and length relative to the radiation dose received. Organ/tissue involvement is related to various radiation dose thresholds as described in Figure 1.

Prodromal signs and symptoms of high-level radiation exposure include anorexia, nausea and vomiting, diarrhea, and mild fever. Conjunctivitis, if the eyes are irradiated and possible skin erythema may be encountered because of the skin dose that often accompanies large acute whole body exposures.

**Figure 1: Acute Radiation Syndromes**




The ARS includes a subclinical phase (< 1 Gy) and three sub-syndromes resulting from whole-body irradiation or irradiation to a significant fraction of the body. The clinical syndromes that result from radiation exposure occur within a predictable

range of doses after whole-body or significant partial-body exposure. These thresholds can be used to approximate the radiation dose based on the patient's signs/symptoms. Below are general thresholds associated with various radiation dose thresholds.

Lymphopenia, neutropenia, and perhaps pancytopenia because of bone marrow aplasia may result in sepsis, hemorrhage, and death.

## Hematopoietic Syndrome

Except for the Sertoli cells of the testes, the mature lymphocytes are the most radiosensitive cells in the human body. The stem/progenitor cells in the bone marrow are also radiation-sensitive. The threshold for hematopoietic syndrome is considered to be >1 Gy, but it is not until greater than 2 Gy that clinically significant hematologic-related illness likely develops. The clinical manifestations will typically occur over a few weeks. At doses beyond the 2-3 Gy range, involvement of various organs can significantly complicate patient management. Lymphopenia, followed by diminution of other blood elements, allows bleeding and infection to occur, thus leading to increased morbidity and mortality.

**Modern supportive care is capable of changing survival of healthy, young person's** receiving an $LD_{50/60}$ dose (50% of the population surviving at 60 days) from 3.5-4 Gy (without medical care) up to 5-6 Gy with supportive care, such the use of transfusions and antibiotics. Supportive care is intended to maintain the patient until surviving islands of stem cells can be stimulated to resume blood cell (neutrophil and platelet) production. The addition of colony stimulating factors (CSFs) and intensive care may raise the $LD_{50/60}$ to 6-8 Gy. The highest survival rates will come from those with 6 Gy doses, or less, without co-morbidities

The need for hematologic support may be prolonged and include blood products, hematopoietic growth factors, and antimicrobials. Combined injuries – acute radiation illness in the presence of physical trauma and/or burns – increase mortality.

## Gastrointestinal Syndrome

GI symptoms may be experienced at approximately 6 Gy. In the dose range beginning around 8 Gy, the GI syndrome becomes more symptomatic with onset of severe nausea, vomiting, and diarrhea. The time to onset of signs/symptoms is dose-related, with a more rapid onset indicating a higher dose.
Additional clinical issues with the gastro-intestinal syndrome can include significant fluid and electrolyte shifts, malabsorption of nutrients, GI bleeding, and sepsis. Once there is depletion of the epithelial cells lining the lumen of the gastrointestinal tract,

bacteria can gain free access to the body, often serving as the impetus for sepsis. Hemorrhage through the denuded areas and sloughing of the bowel can occur. Although death from radiation illnesses in the 8 Gy range has historically occurred within several weeks of the incident, the survival period can be extended considerably with state-of-the-art intensive care.

Although not associated with the GI syndrome, it is worth noting that penetrating radiation doses to the torso in the 6-8 Gy range – and higher – will likely have adverse effects on the pulmonary system.

## Neurovascular Syndrome

The neurovascular syndrome (NVS), sometimes referred to as the cardiovascular/CNS syndrome, occurs at doses on the order of 8 Gy or greater. Nausea and vomiting within minutes and early transient incapacitation has occurred from doses in this range. Following the early incapacitation, there may be a short period of return of some functionality from a few hours up to a few days, followed by a deterioration of the patient's status, the signs/symptoms of which include high fever, prostration, confusion, and decreased blood pressure. This will likely be followed by decreasing consciousness, vascular instability, and death. Convulsions may or may not occur. Cerebral edema and multiple organ pathology are often seen during autopsy. One should be aware that if neurological signs and symptoms occur when it is expected that doses have not exceeded 8 Gy or greater, another etiology for the neurological findings should be sought. Ionizing radiation does not cause neurological findings at lower doses. Acute, irreversible Neurovascular (NV) syndrome occurs at doses > 10 Gy, and mortality approaches 100%.

## Injury to Other Organs

Ionizing radiation may cause injury to the lungs, liver, kidneys, and other organs. Multi-organ failure (MOF) results from maldistribution of blood flow that occurs after radiation-induced systemic inflammatory response syndrome (SIRS). The pathogenesis of MOF is under active investigation.

## Medical Management of ARS

The management of ARS is focused mainly on support and recovery of the hematologic system. Early onset of anorexia, nausea, vomiting, and malaise are indications of higher doses. Two major aims of medical management are efforts to prevent neutropenia and sepsis as heralded by fever. An early collection of blood samples for CBC with differential repeated every 6-12 hours will allow calculation of the absolute lymphocyte count (ALC) and absolute neutrophil count (ANC), with a rapid and deep decrease in the ALC indicating a high dose. As neutropenia worsens,

the risk of infection increases, especially as the absolute neutrophil count drops below 500/mm$^3$. *Patients with radiation-induced immunosuppression often have minimal or absent clinical signs and symptoms of an infection.* Subtle periodontal, pharyngeal, esophageal, perineal, periungual, cutaneous or eye pain/tenderness may be the only clinical findings. Breeches in the skin and GI mucosa permit translocation of bacteria and other infectious agents to the circulation where they flourish in the setting of severe neutropenia and lymphopenia. Reactivation of previous viral infections (including infection with herpes virus and cytomegalovirus) may also occur. Antimicrobial agents should be administered promptly to those with febrile neutropenia, afebrile neutropenia with subtle pain, or clinical signs of infection without neutropenia.

Low-risk patients (defined as having an expected absolute neutrophil count (ANC) of ≤ 500/mm3 for ≤ 7 days, fever of ≥ 38.3 degrees Celsius, hemodynamic stability and no medical co-morbidities) should receive prophylactic oral antibiotics (a fluoroquinolone or amoxicillin/clavulanate), unless they are unable to tolerate oral therapy. In the presence of vomiting or a documented infection, they should receive parenteral antibiotics, using appropriate monotherapy.

**Table 5 - Recommendations for Antibiotic Therapy***

| **Prophylaxis** | **Low Risk Patient** | **High Risk Patient** |
|---|---|---|
| Antibiotics | Ciprofloxacin (Oral) or Amoxicillin/Clavulanate | IV monotherapy with Cefepime, Ceftazidime or Piperacillin/Tazobactam |

| **Bacterial Infection** | **Therapy to Add to Prophylaxis** |
|---|---|
| Pneumonia | Vancomycin or linezolid |
| Skin/Soft Tissue Infections (SSTI) | See latest ISDA recommendations |
| Gram Negative sepsis and/or Gram Negative pneumonia | Aminoglycoside |
| Abdominal symptoms and/or suspected C.Difficile | Metronidazole |

* The guidelines of the Infectious Diseases Society of America should be followed for patients with radiation induced neutropenia (https://www.idsociety.org/Index.aspx).

High-risk patients (defined as having an ANC of ≤ 100/mm3, hemodynamic instability, and one or more one or more of the following issues: such as severe mucositis, I.V. catheter infection, pulmonary infiltrate, chronic pulmonary disease, or changes in mental status. These patients should receive monotherapy that is adjusted based upon specific clinical, imaging, and/or culture findings. Prophylaxis and/or treatment with antimicrobials are indicated for those at risk for infections, e.g., herpes, cytomegalovirus, candidiasis. Selection of treatment regimens for infections should

follow current recommendations of the Infectious Diseases Society of America (IDSA). A consultation with a specialist in infectious diseases is strongly recommended to aid in management of these patients.

**Table 6 - Recommendations for Anti-fungal and Anti-viral Therapy***

| Organism | Serology | Prophylaxis | Active Infection |
|---|---|---|---|
| Candida | N/A | Fluconazole | Fluconazole, Voriconazole or Amphotericin B |
| Herpes Simplex Virus | Positive HSV Type I or II | Acyclovir or Valcyclovir | |
| Cytomegalovirus | CMV Positive | Ganciclovir or Valcyclovir | |

* The guidelines of the Infectious Diseases Society of America should be followed for patients with radiation induced neutropenia (https://www.idsociety.org/Index.aspx).

## Cytokines

Administration of cytokines is beneficial in patients with **hematopoietic syndrome** (HS) who have received a whole-body, absorbed dose of < 5Gy. Filgastrim (Neupogen ®) and its longer-lasting compound, pegylated Filgastrim (Neulasta ®), are approved by the FDA for use in HS to increase survival. The biosimilar agent Leukine requires Emergency Use Authorization (EUA) for use in HS. Whereas daily injections of Filgastrim, beginning within 24-72 hours, are required, biweekly injections of the pegylated form of this agent are sufficient to augment the ANC. A panel of subject matter experts who met at the WHO, Geneva, developed consensus guidelines for management of HS which includes initiation of a cytokine when the ANC is < 500/mm3 and discontinuation when the ANC reaches 1,000/mm3 in the absence of infection (Dainiak N et al., Disaster Med Public Health Prep 2011; 5: 202).

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

- Filgrastim (G–CSF) 10 µg/kg daily subcutaneously
- Sargramostim (GM–CSF) 5–10 µg/kg/d QD subcutaneously or (200–400 µg/$m^2$/d)
- Pegfilgrastim (peg G-CSF) two doses, 6 mg each subcutaneously one week apart

## Clinical Management of the GI Syndrome

Management of the GI syndrome includes administration of a fluoroquinolone (such as ciprofloxacin) or similar antibiotic from 2-4 days after exposure. Parenteral antibiotics and alteration of the bowel flora (reduction in aerobes while maintaining beneficial anaerobes) with oral antimicrobial agents may be useful, if resources permit. Bowel decontamination is not recommended without the concomitant use of intravenous antibiotics. Protracted vomiting should be treated with a serotonin receptor antagonist (5-HT3). In severe cases, enteral or parenteral nutrition. Diarrhea may be controlled with loperamide. Replacement of lost fluids and electrolytes is essential for a favorable outcome.

Acute, irreversible Neurovascular (NV) syndrome occurs at doses > 10 Gy. Since mortality approaches 100%, supportive care is recommended with antiemetic therapy, anti-seizure medications, diuretics (mannitol and furosemide), anxiolytics and analgesics that may include opiate medications at a sufficiently high dose to relieve pain and provide comfort.

## Additional Management Issues for ARS

- Antibiotic, antiviral, and antifungal agents
- Early surgery and wound closure
- Maintain GI anaerobes
- Minimization of invasive procedures
- Strict environmental control with neutropenic precautions
- Consider $H_2$ blockers and proton pump inhibitors for stress ulcer prophylaxis
- Potential benefit for maintaining gastric acidity (sucralfate)
- Oral feeding is preferable to IV, if possible (only cooked foods, no root crops)
- Meticulous oral and nail hygiene

## Conclusion

Early ARS with whole body or significant partial-body irradiation calls for supportive measures, intensive care, cytokine therapy, and antimicrobial therapy as medically indicated. Monitor for impending neutropenia/neutropenic fever and consult IDSA guidelines for antibiotic therapy when appropriate. Consultations with a hematologist/oncologist, an infectious disease specialist, a bone marrow transplant physician, and other medical/surgical subspecialties should be considered.

# Section 4 – Medical Management of Local Injury

## Dose and Clinical Signs

Acute local irradiation injuries may occur separately or co-exist with ARS. This is a common radiation injury in the civilian sector where many radiation devices are in industrial use. Radiation effects associated with a dose threshold are called deterministic effects. Dose thresholds vary amongst differing references. Approximate deterministic thresholds are as follows:

- **3 Gy: Epilation**, typically beginning 2-4 weeks post-incident
- **6 Gy: Erythema** is often transient soon post-incident, with secondary erythema 2-4 weeks thereafter. The pathophysiology for erythema includes arteriolar constriction with capillary dilation and local edema. Erythema may occur in a few hours post-accident (primary erythema), then disappear, only to reappear in the manifest illness phase.

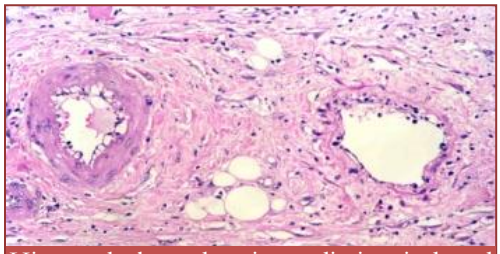

- **10-15 Gy: Dry Desquamation** of the skin is usually seen approximately 2-4 weeks post-incident. There is diminished mitotic activity in cells of the basal and parabasal layers with thinning of the epidermis and desquamation.
- **15-25 Gy: Moist Desquamation** (partial thickness injury) is seen at least 2-4 weeks post-exposure, depending upon dose. In moist desquamation, microscopically, one usually finds intracellular edema, coalescence of vesicles to form macroscopic bullae, and a wet dermal surface coated by fibrin. There is the potential for radionecrosis as the dose increases.
- **For skin dose > 25 Gy**, overt radionecrosis and ulceration secondary to endothelial cell damage and fibrinous necrosis of the arterioles and venules in the affected area. A cutaneous syndrome, arising from high-level whole-body along with local injury, has also been described by various authors.

The medical history is particularly important in diagnosis of the extent of partial-body injury since signs and symptoms generally take days to weeks to manifest. In addition, serial color digital photographs are crucial – preferably photographed against a blue background – along with precise measurement of the lesion to document the evolution of the injury.

In the U.S., diagnosis of high-level skin dose has generally been estimated by observing the serial evolution of symptoms. However, additional diagnostic tools such as cytogenetic dosimetry, MRI, ultrasound visualization of the lesion, and Doppler- or laser-flow profiles have been used.

## Treatment

The key management issues with cutaneous radiation injury are infection control, state-of-the-art wound care, and appropriate pain management. A burn or reconstructive plastic surgeon should be consulted early in the clinical course.



Histopathology showing radiation-induced fibrosis of arteriole: Yanango, Peru case

Radiation-induced skin and organ fibrosis and late skin radionecrosis are delayed complications that are usually considered irreversible. Typical medical management includes eliminating local and general aggravating factors and controlling acute and chronic inflammation with topical steroids. Treatment of local radiation injury resulting in desquamation of the skin includes topical class II-III steroids such as betamethasone, topical antibiotics and topical antihistamines. Topical silver-based products such as sulfadiazine cream may also be use. More severe lesions (chronic ulcerations and necrosis) may require surgical excision of the injured tissue, followed by application of skin grafts with autologous skin and/or flaps, artificial skin (such as Integra®) and/or xenografts. Vascular therapy with pentoxifylline (Trental®) and/or hyperbaric oxygen (HBO) may be effective and pose little risk. Injection of mesenchymal stem cells (MSCs) directly into lesions reduces intractable, neuropathic pain, and appears to promote healing of ulcerations. Controlled trials comparing effects of MSC treatment versus those of traditional surgical procedures are underway.

# Section 5 – Medical Management of Internally Deposited Radionuclides

## Internal Contamination – Early Rapid Assessments

Internal contamination occurs when unprotected personnel ingest, inhale, or are have wounds contaminated with radioactive material. Externally contaminated casualties who did not have respiratory protection should be evaluated for internal contamination. Internal contamination is more likely if significant contamination is found on the face, in/around the nostrils or mouth, or in/around open wounds.

Internal doses are assessed differently than external doses. The two primary differences are: 1) Internal doses are calculated, not measured, and 2) The doses are committed doses. Internal doses are based on the intake, or the amount of radioactive material that initially enters the body. When a bioassay is performed, one can ascertain the activity in the urine, for example, at that particular time. Calculations are then performed to determine how much activity initially entered the body to result in the concentration of radioactive material in the urine at the present time. The same applies to whole body counts, lung counts, or other methods for internal dose assessment.

The concept of committed dose accounts for the fact that internal doses are protracted. The committed dose is the dose received over a fifty year time period due to an internally deposited radionuclide. For regulatory purposes, once the fifty-years-worth of dose is calculated, it is assigned for the year the intake occurred. When the radioactive material deposits into the target organ, it is there until it decays or the body removes it through normal biokinetic processes. These two processes are both at work independently of each other. The effective half-life takes radioactive decay and biological elimination into account. It is calculated by the product of the biological and radioactive half-lives divided by the sum of the two.

A quick way to estimate a radiation dose magnitude from inhalation of radioactive materials is through evaluation of nasal swabs. Samples should be collected by swabbing the anterior nares (separately, with separate swabs) with a cotton swab. Nasal swabs should be taken as soon after the suspected intake as possible, preferably within the first hour. Delays in obtaining nasal swabs will affect intake estimation since the nose clears foreign materials quickly. Each swab should be counted with a hand-held detector and the counts will be added.

Each swab must be counted individually since most people breathe fairly evenly across the nose. Therefore, a significant difference in the count rates may indicate cross-contamination (a contaminated finger?) or deviated nasal septum. Once the combined count rate is converted to an activity (for $\beta/\gamma$ emitters this is usually done by assuming a 10% counting efficiency – until otherwise verified – which means the count rate is divided by 10%, or 0.10) it is assumed to represent 10% of the initial intake. Since regulatory limits – called **Annual Limits on Intake** (ALIs) and found in EPA Federal Guidance Report No. 11 – are based on the intake, the ALIs are an objective benchmark to which to compare patient estimated intake (Sugarman, et al.,

*Health Physics* - June, 2010). Early magnitude estimation for medical decision making is based on U.S. ALIs. International recommendations for intake limitation can also be used for benchmarking.

**Example:** Facial contamination is detected on an individual. Nasal swabs are quickly taken, the sum of which is 150,000 dpm. Therefore, the initial intake is estimated to be 150,000/0.10, or 1,500,000 disintegrations per minute (dpm) – or about 0.7 μCi (~ 26 kBq). Let's assume the contaminant is $^{137}$Cs. The inhalation ALI for $^{137}$Cs is 200 μCi (7.4 MBq). Our estimate is significantly below the U.S. annual regulatory limit so this intake is not expected to be medically significant. Again, the ALI as used here is a U.S. regulatory limit, not a medically derived limit. It does, however, make for a good comparison point that can help guide early medical management.

In a case where the radioisotope is unknown, if the emission (α, β, γ) can be determined, one can make an assumption regarding the isotope of interest. For example, if an unknown alpha-emitter is encountered, until the isotope can be identified, assuming it is $^{241}$Americium is usually a safe bet for dose magnitude estimation purposes (see Table 7). It may not always be correct, but it ought to get the magnitude estimation in the right neighborhood. ALIs for common isotopes can be found below. Again, this is a method to help determine dose magnitude and is therefore essentially a triage tool. It is not intended to determine an accurate internal radiation dose, therefore estimates should be verified by appropriate bioassay techniques.

**Table 7 – U.S. Inhalation ALIs for Assumed Radionuclides**

| Emission | Assumed Radionuclide | US ALI and solubility class | ~ dpm |
|---|---|---|---|
| Alpha | Am-241 | 0.006 μCi/0.2 kBq - W | $1.3 \times 10^4$ |
| Beta | Sr-90 | 4 μCi/0.148 MBq- Y | $8.9 \times 10^6$ |
| Gamma | Cs-137 | 200 μCi/7.4MBq - D | $4.4 \times 10^8$ |

** Most restrictive ALI values from FGR-11 are listed. μCi activities converted to MBq (slightly different than FGR-11)*

**Table 8 - U.S. Inhalation ALIs for Specific Radionuclides**

| Nuclide | US ALI and Solubility Class | ~ dpm |
|---|---|---|
| H-3 | 80,000 μCi/3 GBq ($H_20$ Vapor) | $1.8 \times 10^{11}$ |
| Co-60 | 30 μCi/1.1 MBq - Y | $6.7 \times 10^7$ |
| U-235, 238 | 0.04 μCi/1.48 kBq - Y | $8.9 \times 10^4$ |
| Pu-239 | 0.006 μCi/0.2 kBq - W | $1.3 \times 10^4$ |
| Cf-252 | 0.02 μCi/0.74 kBq - W | $4.4 \times 10^4$ |

** Most restrictive ALI values from FGR-11 are listed. μCi activities converted to MBq (slightly different than FGR-11)*

Many radiation protection professionals may not be aware of the **Clinical Decision Guides** (CDGs) introduced in NCRP Report No. 161, Management of Persons Contaminated with Radionuclides (2009). The CDG can be used as an alternative to the ALI as a comparison point when assessing internal dose magnitude. It is intended to provide a measurement a physician can use to help guide his/her decision regarding recommendations of the use of medical countermeasures after an intake of radioactive materials.

The CDG considers the stochastic risk based on effective dose over 50 years for adults or until age 70 for children. The stochastic risks considered are in the range of risks associated with the dose recommendations for emergency responders found in the EPA PAG Manual (Protective Action Guides and Planning Guidance for Radiological Incidents). The avoidance of deterministic effects based on 30-day RBE-weighted marrow and lung doses is also considered in the formulation of the CDG for a specific radioisotope. For radioiodine it is defined somewhat differently because the organ at primary risk is the thyroid gland, and the FDA has provided specific guidance for projected thyroid doses. CDGs are provided for inhalation and ingestion intakes. Obviously, nasal swab results should only be compared to inhalation CDGs. For a more detailed definition of the CDG and its associated dose parameters, NCRP Report No. 161 should be consulted. Table 9 provides an example of the information provided in the CDG tables found in Part C, Section 11 of NCRP Report No. 161.

**Table 9 - Selected CDG Information from NCRP-161**

| Radioisotope | Method of Intake | Form | Activity in urine (0-24 hr) indicative of 1 CDG (dpm) | Activity on nasal swabs soon after inhalation indicative of 1 CDG (dpm)* |
|---|---|---|---|---|
| Co-60 | Inhalation | Type M | 4.2E+7 | 1.1E+8 |
| Co-60 | Inhalation | Type S | Not recommended | 4.4E+7 |
| Sr-90 | Inhalation | Type F | 3.4E+7 | 2.5E+7 |
| Sr-90 | Ingestion | Soluble | 3.0E+7 | NA |
| Cs-137 | Inhalation | Type F | 7.7E+7 | 1.7E+8 |
| Cs-137 | Ingestion | Soluble | 7.6E+7 | NA |
| Pu-239 | Inhalation | Type M | 9.6E+1 | 2.3E+4 |
| Pu-239 | Inhalation | Type S | 3.8E0 (supplement with fecal) | 8.9E+4 |
| Am-241 | Inhalation | Type M | 1.0E+3 | 2.8E+4 |

* Assumes 5% of the intake is found on the swabs.
Sampling time post-intake is only defined as "early hours".

Open wounds present another route for radioactive contamination to enter the body. NCRP Report No. 156, Development of a Biokinetic Model for Radionuclide-Contaminated Wounds and Procedures for their Assessment, Dosimetry, and Treatment (2006) was consulted to calculate dose conversion factors for various radioisotopes and contaminant/wound types using the Activity and Internal Dose Estimates (AIDE, Bertelli) internal dosimetry software. Dividing the applicable regulatory dose limit by the corresponding dose conversion factor (DCF) results in what can be termed a derived reference level (DRL) – similar to an ALI, which is not defined for wounds (Toohey, et al., Health Physics – May, 2011).

The DRL can be used as a reference point in much the same way as the ALI is used above. To apply this concept simply obtain an early wound count, convert the count rate to an activity (dpm), and compare it to the appropriate DRL below. Remember that just because the contamination levels are higher than the DRL does not necessarily mean there is a significant medical issue, but simply that the contamination levels may result in an internal dose close to the regulatory limit.

Please note that Table 10 is based upon US dose limits, but the dose conversion factors were based on effective dose (international guidance). This should not affect the use of this table for dose magnitude estimation. Remember, the point is to determine a point with which comparisons can be made that can then be used to help guide medical decisions. International guidance will use different dose limits resulting in different DRLs (20 mSv – or 2 rem – divided by the appropriate DCF). Refer to NCRP No. 156 or contact REAC/TS for further guidance.

**Table 10 - Selected DRLs for Defined Solubility Class (dpm)**

| Isotope | Based on* | Weak | Moderate | Strong | Avid |
|---|---|---|---|---|---|
| Co-60 | ED | 1.54E+08 | 1.54E+08 | 1.65E+08 | 2.01E+08 |
| Sr-90 | BS | 2.20E+07 | 2.20E+07 | 2.25E+07 | 2.38E+07 |
| Tc-99m | ED | 2.00E+11 | 2.56E+11 | 9.33E+11 | 8.78E+11 |
| I-131 | Thy | 7.06E+07 | 8.01E+07 | 1.26E+08 | 3.46E+08 |
| Cs-137 | ED | 2.20E+08 | 2.20E+08 | 2.23E+08 | 2.34E+08 |
| Ir-192 | ED | 4.49E+08 | 4.66E+08 | 6.21E+08 | 1.69E+09 |
| U-235 | BS | 8.23E+05 | 8.23E+05 | 8.29E+05 | 8.46E+05 |
| U-238 | BS | 8.55E+05 | 8.55E+05 | 8.63E+05 | 8.78E+05 |
| Pu-239 | BS | 1.81E+03 | 1.81E+03 | 1.85E+03 | 1.92E+03 |
| Am-241 | BS | 1.65E+03 | 1.65E+03 | 1.68E+03 | 1.74E+03 |
| Cf-252 | BS | 5.14E+03 | 5.15E+03 | 5.75E+03 | 7.96E+03 |

** ED = Effective Dose, BS = Bone Surface, Thy = Thyroid*
*ED reference point = 5 rem (committed), Organ dose reference point = 50 rem (committed)*

## Medical Management of Internal Contamination

Medical management is specific and isotope-dependent; therefore identifying the isotope is crucial. Both radioactive decay and biological elimination rid the body of radioactive materials. Combining both elimination rates provides the effective half-life, which is always shorter that either the radiological or biological half-life. Metabolism and elimination kinetics of the non-radioactive analog determine the metabolic pathway of the radionuclide. The major routes of intake are inhalation, ingestion, absorption through an open wound contamination, and transdermal absorption. Dissolution of uranium from embedded DU shrapnel has also been noted.

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

- Reduction and/or inhibition of absorption of the isotope in the GI tract. Examples: Prussian blue, barium sulfide.
- Blocking uptake to the organ of interest. Example: Within 4-6 hours of exposure, administer potassium iodide (KI) to block uptake of radioactive iodine by the thyroid.
- Isotopic dilution. Example: Increase fluid hydration for internal tritium contamination.
- Altering the chemistry of the substance. Example: Prevent binding of uranyl ions with the renal tubule surface proteins by use of sodium bicarbonate that causes alkalinization of the urine.
- Displacing the isotope from receptors. Example: Using calcium to compete with strontium.
- Chelation techniques. Example: Administer DTPA for internal deposition of plutonium.
- Early excision of radionuclides from wounds to minimize absorption.
- Bronchoalveolar lavage for severe cases of insoluble inhaled particles. This would be a technique rarely used and expected only in a case with a very large lung burden of an insoluble alpha emitter such as plutonium.

There are over 8,000 isotopes, but only 10-15 are considered to be important in the military and civilian sectors, and with regard to terrorism and to industrial accidents. Certain isotopes fall into general categories of interest as noted below:

**"University Five"** – $^{14}C$, $^{32}P$, $^{125}I$, $^{131}I$, $^{252}Cf$: Used for isotopic labeling in biochemistry laboratories, and in medicine. Tritium is also common.
**"Industrial Three"** – $^{192}Ir$, $^{137}Cs$, $^{60}Co$: $^{192}Ir$ is widely used in industrial radiography to photograph large objects such as oil pipes, airplane wings, etc. $^{137}Cs$ and $^{60}Co$ are

used in industry because of their penetrating gamma rays and are considered to be prime agents for terrorism incidents.
**"Military Five"** – Tritium ($^{3}H$), $^{235}U$, $^{238}U$, $^{239}Pu$, and $^{241}Am$: Isotopes primarily used in the weapons complex, both in the DOE system and in the military.
**Fission/Activation Products** – encountered in response to a nuclear detonation – either an IND or a weapon – a reactor accident, or a waste transportation incident. Some are volatile and, depending on the activity, can pose a significant risk to the populace.

NCRP Report No. 65 (1980) is widely considered an important reference document for physicians who need to employ decorporation therapy in patients with internal deposition of radioactive materials. NCRP Report No. 161 (2010) provides significant additional information and health physics guidelines for the management of internal contamination. It introduces a dose/risk based term, Clinical Decision Guide (CDG), that can be used to help physicians decide when to treat, or not to treat.

NCRP Report No. 161 also addresses the use of spot urine samples. Care should be taken when analyzing spot urines for a number of reasons including, but not limited to 1) Has there been adequate time for the radionuclide to become systemic and to allow for excretion? 2) If using a handheld meter for counting the specimen, is the radiation of a type that can be detected? 3) Is the excretion pathway appropriate for the chemical compound of interest? The data in Tables 11 and 12 are adapted from NCRP Report No. 161.

## Therapy for Specific Radionuclides

This section provides (1) recommendations for decorporation therapy for specific radionuclides, and (2) drug information for treatment. Table 11 summarizes treatment recommendations for various radionuclides of concern in the medical management of internal contamination. Table 12 provides dose schedules for drug or treatment modalities. As stated in *Generic Procedures for Medical Response During a Nuclear or Radiological Emergency* (IAEA, 2005), when deciding on the treatment for internal contamination comparison is to be made between the benefit of removing the radioactive contaminants using modalities associated with significant side effects and the short- and long-term health effects of the internalized radioactive materials without treatment.

| Table 11 - Decorporation Therapy Recommendations in the USA for Radionuclides of Concern (NCRP Report 161, 2010). | | |
|---|---|---|
| **Radionuclides** | **Alternate Treatment** | **Preferred Treatment** |
| Actinium (Ac) | Consider DTPA | Consider DTPA |
| Americium (Am) | DTPA | DTPA |
| Antimony (Sb) | BAL, penicillamine | BAL |
| Arsenic (As) | BAL, DMSA | BAL |
| Barium (Ba) | Ba, Ca Therapy | See NCRP 161 |
| Berkelium (Bk) | DTPA | DTPA |
| Bismuth (Bi) | BAL, penicillamine, DMSA | DMSA |
| Cadmium (Cd) | DMSA, DTPA, EDTA | DMSA |
| Californium (Cf) | DTPA | DTPA |
| Calcium (Ca) | Ba, Ca Therapy | See NCRP 161 |
| Carbon | No treatment available | N/A |
| Cerium (Ce) | DTPA | DTPA |
| Cesium (Cs) | Prussian blue | Prussian blue |
| Chromium (Cr) | DTPA, EDTA (antacids are contraindicated) | DTPA |
| Cobalt (Co) | DMSA, DTPA, EDTA, NAC | DTPA |
| Copper (Cu) | EDTA, penicillamine, trientine | Penicillamine |
| Curium (Cm) | DTPA | DTPA |
| Einsteinium (Es) | DTPA | DTPA |
| Europium (Eu) | DTPA | DTPA |
| Fission Products (Mixed) | Management depends on predominant isotopes present at time. Early: iodine; Late: strontium, cesium, and others | |
| Fluorine (F) | Aluminum hydroxide | Aluminum hydroxide |
| Gallium (Ga) | Consider penicillamine | Penicillamine |
| Gold (Au) | BAL, penicillamine | BAL |
| Indium (In) | DTPA | DTPA |
| Iodine (I) | Potassium iodide (KI), propylthiouracil, methamizole | KI |
| Iridium (Ir) | Consider DTPA, EDTA | Consider DTPA |
| Iron (Fe) | Deferoxamine (DFOA), deferasirox, DTPA, DFOA and DTPA together | DFOA |
| Lanthanum (La) | DTPA | DTPA |

| Table 11 - Decorporation Therapy Recommendations in the USA for Radionuclides of Concern (NCRP Report 161, 2010). | | |
|---|---|---|
| **Radionuclides** | **Alternate Treatment** | **Preferred Treatment** |
| Lead (Pb) | DMSA, EDTA, EDTA with BAL | DMSA |
| Manganese (Mn) | DFOA, DTPA, EDTA | DTPA |
| Magnesium (Mg) | Consider strontium therapy | Consider strontium therapy |
| Mercury (Hg) | BAL; EDTA; penicillamine; DMSA | BAL |
| Molybdenum (Mo) | Limited clinical experience | |
| Neptunium (Np) | Consider DFOA and/or DTPA | Consider DFOA and/or DTPA |
| Nickel (Ni) | BAL, EDTA | BAL |
| Niobium (Nb) | DTPA | DTPA |
| Palladium (Pd) | Penicillamine, DTPA | Penicillamine |
| Phosphorus (P) | Phosphorus Therapy | Phosphorus therapy |
| Plutonium (Pu) | DTPA, DFOA, EDTA, DTPA and DFOA together | DTPA |
| Polonium (Po) | BAL, DMSA, penicillamine | BAL |
| Potassium (K) | Diuretics | Diuretics |
| Promethium (Pm) | DTPA | DTPA |
| Radium (Ra) | Ra, Sr therapy | |
| Rubidium (Rb) | Prussian Blue | Prussian Blue |
| Ruthenium (Ru) | DTPA, EDTA | DTPA |
| Scandium (Sc) | DTPA | DTPA |
| Silver (Ag) | No specific therapy. Consider gastric lavage and purgatives. | |
| Sodium (Na) | Diuretic and isotopic dilution with 0.9 % NaCl | Diuretic and isotopic dilution with 0.9 % NaCl |
| Strontium (Sr) | Ra, Sr therapy | |
| Sulfur (S) | Consider sodium thiosulfate | Consider thiosulfate |

| Table 11 - Decorporation Therapy Recommendations in the USA for Radionuclides of Concern (NCRP Report 161, 2010). | | |
|---|---|---|
| **Radionuclides** | **Alternate Treatment** | **Preferred Treatment** |
| Technetium | Potassium perchlorate | Potassium perchlorate |
| Thallium (Tl) | Prussian Blue | Prussian Blue |
| Thorium (Th) | Consider DTPA | Consider DTPA |
| Tritium ($^{3}H$) | Force fluids | Water diuresis |
| Uranium (U) | Bicarbonate to alkalinize the urine. Consider dialysis | Bicarbonate |
| Yttrium | DTPA, EDTA | DTPA |
| Zinc (Zn) | DTPA, EDTA, Zinc sulfate as a diluting agent | DTPA |
| Zirconium (Zr) | DTPA, EDTA | DTPA |

| Table 12 - Dose Schedules for Drug or Treatment Modalities. | |
|---|---|
| **Drug or Treatment Modality** | **Dosage** |
| Acetylcysteine (NAC) | FDA does not specify age, IV 300 mg/kg in 5% dextrose in water over 24 hours for acetaminophen overdosage. |
| Deferoxamine (DFOA) | FDA does not specify age: Deferoxamine mesylate injectable (DFOA); IM is preferred. 1 g IM or IV (2 ampules) slowly (15 mg $kg^{-1}$ $h^{-1}$); Repeat as indicated as 500 mg IM or IV q4h × 2 doses; then 500 mg IM or IV every 12 hours for 3 days. |
| Dimercaprol (BAL) | FDA does not specify age: IM: 300 mg per vial for deep IM use, 2.5 $mg^{-1}$ kg (or less) every 4 hours for 2 days, then twice daily for 1 day then daily For days 5 – 10 |

| Table 12 - Dose Schedules for Drug or Treatment Modalities. | |
|---|---|
| **Drug or Treatment Modality** | **Dosage** |
| Diethylenetriaminepentaacetate (DTPA, calcium or zinc) | Adults: IV: 1 g in 5 mL slow IV push (SIVP) over 3-4 minutes or IV infusion over 30 minutes diluted in 250 mL of 5 % dextrose in water, Ringers Lactate or Normal Saline (NS)<br><br>Children under 12 years: 14 mg $kg^{-1}$ IV as above, not to exceed 1.0 g<br>IM: 1 g can be given with procaine to reduce pain (not FDA approved)<br><br>Nebulized inhalation: 1g in 1:1 dilution with sterile water or NS (for treatment of inhaled isotope, use caution with underlying respiratory disease and pediatrics) |
| Edetate calcium disodium (EDTA) | FDA does not specify age: Ca-EDTA (edetate calcium disodium); 1,000 mg $m^{-2}$ $d^{-1}$ added to 500 mL $D_5NS$ infused over 8 – 12 hours. |
| Penicillamine | FDA does not specify age: Oral: 250 mg daily between meals and at bedtime. May increase to 4 or 5 g daily in divided doses. |
| Phosphorus Therapy<br>Potassium phosphate, dibasic | Oral: 250 mg phosphorus per tablet.<br>Adults: 1 – 2 tabs oral four times daily with full glass of water each time, with meals and at bedtime.<br>Children over 4 years: 1 tab oral four times daily. |
| Potassium iodide (KI) | Oral: tablets or liquid. Drug dose varies between 16 mg and 130 mg daily depending on age, thyroid exposure level, and whether or not pregnant or lactating. |
| Propylthiouracil (PTU) | Oral: 50 mg tabs, 2 tabs three times daily for eight days. FDA does not specify age. |
| Prussian Blue | Oral: Adults and Adolescents 3 g three times daily.<br>Children 2 – 12 years: 1 g three times daily. |

| Table 12 - Dose Schedules for Drug or Treatment Modalities. | |
|---|---|
| **Drug or Treatment Modality** | **Dosage** |
| Sodium bicarbonate (for uranium only) | Oral or IV to alkalize urine |
| Radium and Strontium Therapy | Aluminum hydroxide: PO: 60 – 100 mL once.<br><br>10% Calcium chloride suspension. Adults: IV: 200 mg to 1 g every 1 – 3 d, slow IV, not to exceed 1 mL/min<br><br>Calcium gluconate. PO: 10 g powder in a 30 cc vial, add water and drink |
| Succimer (DMSA) (Chemet®) | FDA approved pediatric dosing: Start dosage at 10 mg kg–1 or 350 mg m–2 oral every 8 hours for 5 days. Reduce frequency of administration to 10 mg kg–1 or 350 mg m–2 every 12 hours (two-thirds of initial daily dosage) for an additional 2 weeks of therapy. A course of treatment lasts 19 days. |
| Water diuresis | Oral: Fluids more than 3 – 4 L d–1 |

## KI Blockage of the Thyroid

Children are particularly susceptible to the potential for thyroid cancer following exposure to radioactive iodine. The uptake of radioactive iodine should be blocked by administering oral potassium iodide (KI) within 4 hours of exposure. Some people may be allergic to KI. There are alternatives to KI, but they should be discussed with the individual's personal physician.

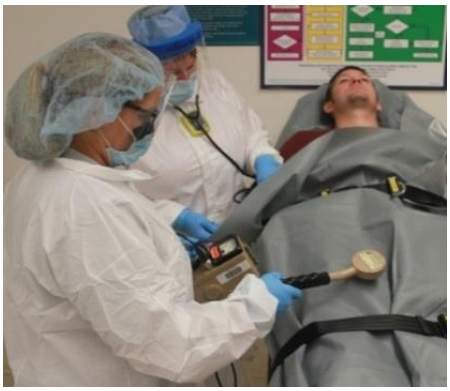
Some major US cities have considered the issue of stockpiling KI. Radioactive iodine is likely to be released from a nuclear reactor undergoing a catastrophic accident and potassium iodide is a means to block radioactive iodine from being absorbed by the thyroid gland. The concentration of radioiodine in the air depends partially on distance from the plant, atmospheric conditions, wind direction and the release rate. The most sensitive population includes fetuses and those less than 18 years of age with females exhibiting more sensitivity than males. Expert advisory panels have been convened to determine whether KI pre-distribution and stockpiling is efficacious to protect the health of citizens in a large city.

| Table 13 - Potassium Iodide Recommended Doses | |
|---|---|
| **Adults >40 years of age**<br>with thyroid exposure ≥ 5 Gy (500 rad) | 130 mg daily |
| **Adults 18 – 40 years of age**<br>with thyroid exposure ≥ 0.1 Gy (10 rad | 130 mg daily |
| **Pregnant or lactating women**<br>with thyroid exposure ≥ 0.05 Gy (5 rad) | 130 mg daily |
| **Children and adolescents 3–18 years of age**<br>with thyroid exposure ≥ 0.05 Gy (5 rad | 65 mg daily |
| **Infants 1 month – 3 years of age**<br>with thyroid exposure ≥ 0.05 Gy (5 rad) | 32 mg daily |
| **Neonates from birth – 1 month**<br>with thyroid exposure ≥ 0.05 Gy (5 rad) | 16 mg daily |

The robust engineering and safety systems of current US nuclear plants would allow for about 48 hours of emergency preparation before a release would occur. Even under that circumstance, inhalation of radioactive iodine at levels triggering use of KI is almost impossible to achieve due to distance from the plant and the dispersal of the plume. The hazard to residents and visitors is almost totally through the food chain where radio-iodine might deposit on cultivated vegetables and enter milk via dairy cows consuming contaminated grass. Response actions are designed to circumvent this hazard through a food interdiction program that involves the cooperation of farms and dairies. Advisory groups have concluded on scientific grounds alone that there is little to no health benefit gained by stockpiling, pre-distributing and/or distributing KI post-accident.

# Section 6 – Decontamination Techniques

## Safety of Healthcare Personnel



Radiologically contaminated patients generally pose no danger to healthcare personnel. Implementation of universal precautions is an effective action for protection against contamination as demonstrated during the medical response to the Alexander Litvinenko contamination event. The radiation exposure hazard from a radiologically contaminated casualty will very likely be minimal, so necessary medical or surgical treatment must not be delayed because of possible contamination.

## Initial Management

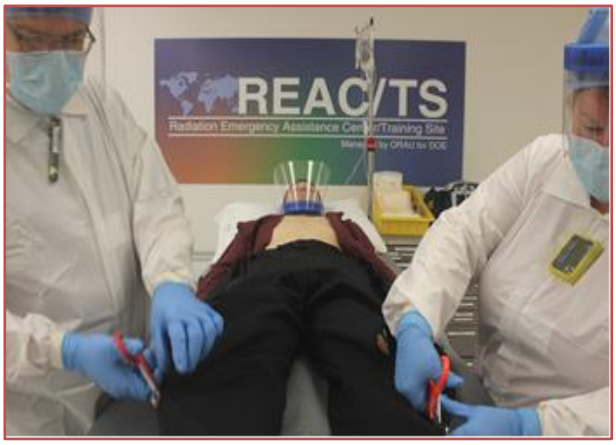
The initial management of a patient contaminated by radioactive materials is to perform all immediate life-/limb-saving actions without regard to contamination. Decontamination should not interfere with medical care and contaminated casualties should not be barred entry to a medical facility if entry is necessary for life-saving care. Casualties entering a medical unit after a radiological incident should be considered contaminated unless verified as non-contaminated. A quick head-to-toe survey should provide sufficient evidence of the presence or absence of gross contamination. This can usually be done as medical personnel are assessing the medical stability of the patient. Radiological decontamination, that is, the removal of radioactive materials from surfaces, often demands significant resources and can take substantial time.

## Decontamination Techniques

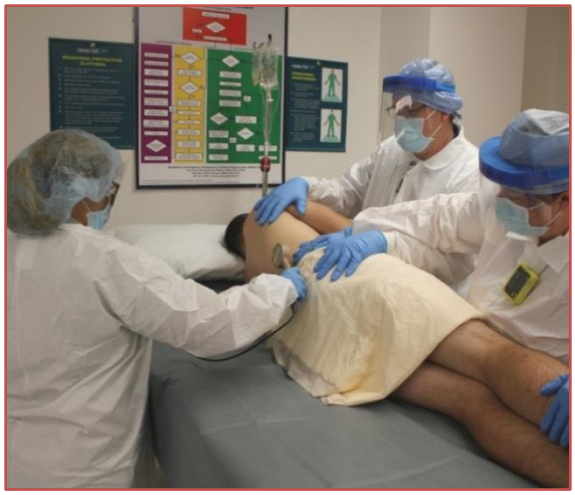
Gross radioactive contamination is typically fairly easily detected via a quick scan of the patient with appropriate instrumentation. Radiological decontamination is performed in a very similar manner to doctrinal chemical decontamination. The main difference is in timing. Chemical decontamination is often an emergency. Radiological decontamination is not an emergency. Decontamination should follow basic common sense. Unlike chemicals, radioactive materials cannot be "neutralized." They can only be moved from one point to another. Radiological decontamination should be performed with that in mind. Therefore, the challenge is to remove the radioactive material from one area and transfer it to where you want it to be without spreading it to points in between.

***The first priority is to ensure the patient is medically stable.***

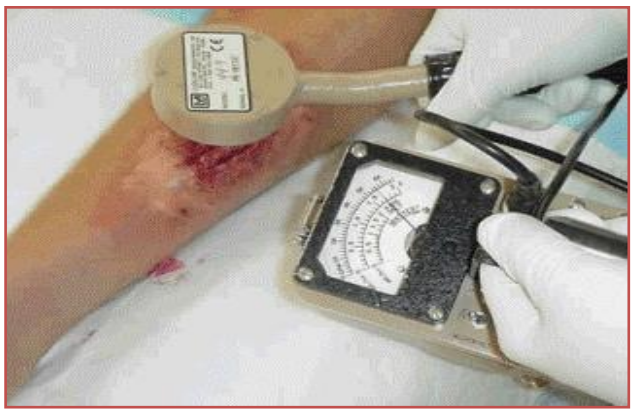
Once the patient has been medically stabilized the first step is clothing removal. It stands to reason that clothing typically covers a large percentage of one's body, so properly removing the clothing will likely significantly decrease the amount of radioactive material with which the healthcare provider has to contend. This is done by cutting, not tearing, the clothing in a direction away from the patient's airway and rolling it outward away from the patient's skin, trapping the material in the clothing. If the patient is amenable, a splash shield may be applied.



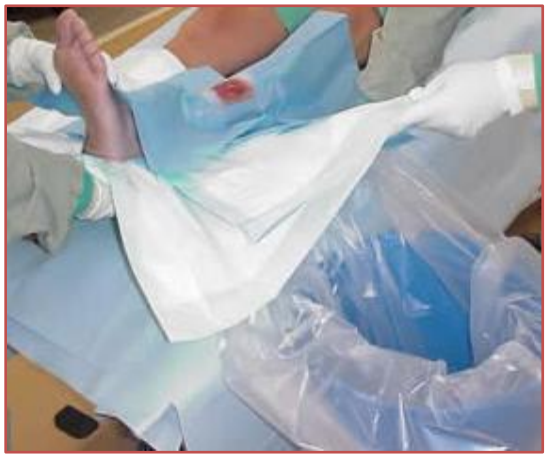

Once the clothing has been cut, a log-roll procedure can be used to remove the clothing. In the following picture multiple sheets have been placed on the bed. The top sheet is folded over the clothing creating a clean surface onto which the patient can be rolled. The patient is then rolled to the other side where the sheet is folded over the clothing and then removed from the bed by rolling it toward the feet. Once the sheet is removed a quick radiological survey can be performed of the back looking for any obvious areas of contamination. At this point the overall contamination levels should be significantly reduced. Be sure to bag the clothing/top sheet and send it out for sampling. This is an excellent representation of the types of radioactive materials that may have to be dealt with when evaluating internal contamination.



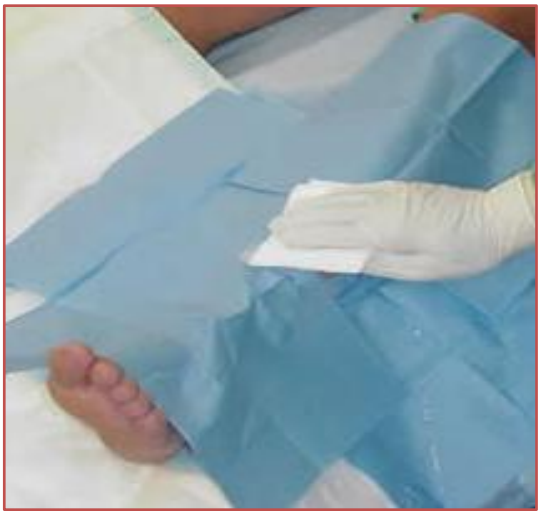
Decon priorities are 1) wounds, 2) body orifices around the face, and 3) intact skin. In order to address the contaminated wound one should prepare the area for decontamination. The intact skin immediately adjacent to the wound should be quickly decontaminated using a baby-wipe (wipe away from the wound). This is done to minimize any contamination that may get transferred back into the wound and to ensure that contamination in this area is not confused with the actual counts in the wound.



Finally, drapes should be applied to the area to prevent the spread of contamination to uncontaminated areas. After the draping is properly applied wound decon can begin. Gently irrigate the wound using sterile saline or something similar. The purpose of the initial irrigation is to attempt to remove the bulk of the contamination, so do not be too aggressive in order to prevent splashing and potentially spreading contamination. The runoff should be directed into a receptacle – a lined garbage can usually works well. It may also be a good idea to attempt to collect the runoff at the wound site via the use of absorbent pads. All waste generated should be kept in a pre-arranged location for later collection and disposal.



Repeat contamination surveys to determine the effectiveness of the decontamination attempts. The wound should be covered as the drapes are removed and a clean, absorbent pad should be placed under the affected area prior to resurvey.

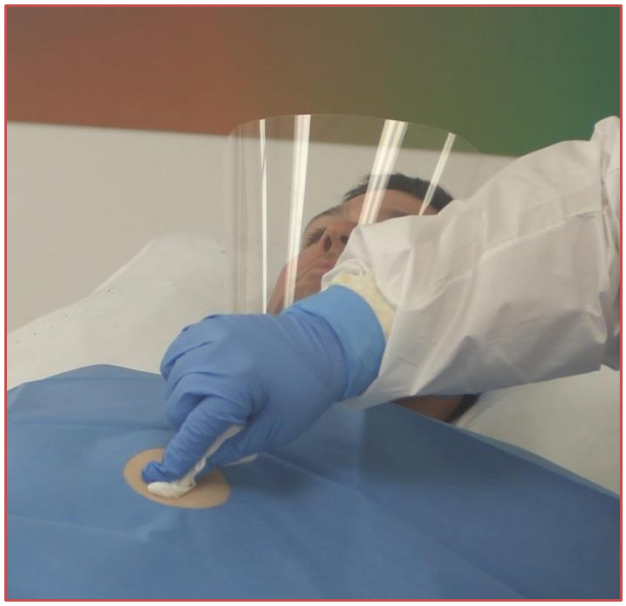


If the wound is still contaminated the process should be repeated until no further progress is made. Should the contamination levels continue to be elevated and decontamination progress is overly slow or nonexistent, the wound should be explored for foreign bodies by the treating physician. Minor debridement may be necessary. Keep in mind that wounds will still need to be irrigated before closure for infection control purposes. This may remove the remaining contamination. In general, small amounts of contamination in a wound do not override the concerns for proper infection control and cosmetic effect.

Decontamination of body orifices in and around the face poses a challenge in that easily applied methods are limited. Many times the nares can be decontaminated simply by having the patient blow his/her nose. Prior to irrigation of the nares, consideration should be given to the risk of forcing more radioactive material into the body via the oropharynx as a result of this procedure. Routine methods used to irrigate the eyes are acceptable, but care should be taken to ensure the run-off is directed away from the nose/mouth and to prevent it from entering the ears.

When decontaminating the skin, care should be taken to avoid visible irritation. Abrading the skin may allow an entry point for radioactive materials deposited on its surface. When performing skin decontamination it is always better to start with the simplest method available. One good option that generates very little waste is the use of baby-wipes. If baby-wipes do not work, more aggressive steps may be taken. One should take care to maintain the integrity of the skin. Gently scrubbing with a soft cloth and tepid water and soap is another option.

The cleaning motion should go from the outside in, much like cleaning up a paint spill. The goal is to minimize the area of contamination, not to spread it outwardly. It may be helpful to drape the area and set up a collection basin, much like is done when decontaminating a wound, if large amounts of fluids are going to be used for irrigation.




Should hair become contaminated it can be washed, taking care not to allow the wash/rinse water to run onto the face. On areas such as hairy chests it is best not to shave the area since this may lead to skin abrasions. Clipping the hair is a better idea, but only if necessary. Keep in mind that the patient may be averse to having his/her hair cut.

Bare skin and hair should be thoroughly washed, and if practical, the effluent should be sequestered and disposed of appropriately. Excision of wounds is appropriate when surgically indicated. Radioactive contaminants in the wound surfaces will likely be removed with the tissue.

# Section 7 – Biodosimetry

Biodosimetry is the use of a biological response as an indicator of radiation dose. Cytogenetic biodosimetry is considered the "gold standard" for determination of patient whole-body radiation dose. For inquiries regarding biodosimetry call REAC/TS at (865)576-3131.

## Early-Response Multi-Parameter Biodosimetry

No single assay is sufficiently robust to address all potential radiation scenarios, including management of mass casualties and diagnosis for early medical treatment. Recommendations for use by first responders and first receivers involve a prioritized multiple-assay biodosimetric-based strategy. NCRP Commentary No. 19 (NCRP, 2005) recommends multi-parameter triage (*i.e.*, time to vomiting, lymphocyte depletion kinetics, and other biodosimetry and biochemical indicators) as the current best early biodosimetric assessment of a victim's absorbed dose. Biodosimetry is not intended to replace physical dose estimation, but to provide additional information on an individual's biological dose. The biological dose supplements other methods of dose assessment such as rapid dose estimation and formal dose reconstruction.

From Table 14, it is evident that emesis within 1-2 h can be particularly serious while a drop in lymphocyte count to 1/2 or 1/3 of baseline values within 24 hours signals a potentially lethal situation. After 24 h, increases in serum amylase are also potentially confirmative. As noted below, early, rapid deployment, high-throughput cytogenetic dosimetry utilizing the internet is expected to be very valuable in triage of large numbers of people. Conversely, from the time-to-emesis data, if a patient has not vomited in 8-10 h, then any dose is very likely less than 1 Gy and he/she can be moved to outpatient facilities.

### Table 14 – Multiple Parameter Biodosimetry

| Dose, Gray (Gy) | Percent of people with emesis | Median onset of emesis (hours) | Absolute Lymphocyte count; % of normal in first 24 h | Number of dicentrics per 50 metaphases |
|---|---|---|---|---|
| 0 | - | - | 100 | 0.05-0.1 |
| 1 | 19 | - | 88 | 4 |
| 2 | 35 | 4.6 | 78 | 12 |
| 3 | 54 | 2.6 | 69 | 22 |
| 4 | 72 | 1.7 | 60 | 35 |
| 5 | 86 | 1.3 | 53 | 51 |
| >6 | 90-100 | 1.0 | < 47 | - |

Biodosimetry Based on Acute Photon-Equivalent Exposures; Waselenko, JK, "Medical Management of the Acute Radiation Syndrome: Recommendations of the Strategic National Stockpile Radiation Working Group", Ann Intern Med, 2004.

Biodosimetric guidelines recommended by REAC/TS include documentation of:

- Clinical signs and symptoms
- Radioactivity assessment
- CBC and differential for calculation of absolute lymphocyte and neutrophil counts
- Platelet count
- Personal survey for contamination and area dosimetry
- Cytogenetics

Other tests that may provide supplemental information that have been recommended in consensus guidelines include:

- Electron paramagnetic resonance (EPR)-based dose assessment of teeth, nails and hair
- Levels of circulating amylase, C-reactive protein (CRP), FLT-3 ligand, and citrulline

Tests under development include profiles of gene expression, metabolites and protein.

## Cytogenetic Biodosimetry

Cytogenetic biodosimetry has been used for decades to estimate dose on the basis of radiation-induced chromosome aberrations in circulating lymphocytes. It is mainly applicable to recent whole-body acute radiation exposures. Because of the low background level of dicentric chromosomes in lymphocytes the assay's sensitivity is comparatively high, with a threshold whole-body dose of 0.1 Gy (based on analysis of 1,000 cells), and it shows a strong dose dependence up to 5 Gy for acute photon exposures. The reproducibility, relative specificity of dicentric aberrations to radiation, and its sensitivity to doses below acute medical significance have allowed the assay to become the "gold standard" of radiation biodosimetry. One drawback is that the standard method of scoring 500-1000 metaphase spreads requires about 4 to 5 days, including timely transport to the laboratory, processing and scoring the sample, and providing a dose estimate. Most scorers will therefore be able to evaluate no more than ~300 metaphase cells per day. Studies at REACTS, however, have demonstrated that "remote" scorers in distant locations can utilize the internet to share the work load, overcome the "bottleneck" inherent in scoring cells, and thereby reduce the time to generate dose estimates.

Many laboratories have automated metaphase finders in routine use which speeds up the process by quickly locating scoreable cells. In addition, triage testing has demonstrated that scoring as few as 50 cells per sample can produce dose estimates

within +/- 0.5 Gy of the true dose 9 out of 10 times. This level of accuracy is generally considered sufficient to guide the initial clinical treatment decisions.

| Table 15. Guidance on Choice of Biodosimetry Methods | | |
|---|---|---|
| **Dose Range (Gy)** | **Recommended Dosimetry Method** | **Clinical Symptoms** |
| 0.1 - 1 | Dicentric assay | None to slight decrease in blood count |
| 1.0 - 3.5 | Lymphocyte depletion kinetics/dicentrics | Mild to severe bone marrow damage |
| 3.5 - 7.5 | Lymphocyte depletion kinetics/PCC | Pancytopenia, mild to moderate GI damage |
| 7.5 - 10.0 | Lymphocyte depletion kinetics/PCC | Bone marrow and GI damage |
| > 10.0 | PCC | GI, neurological, and cardiovascular damage |

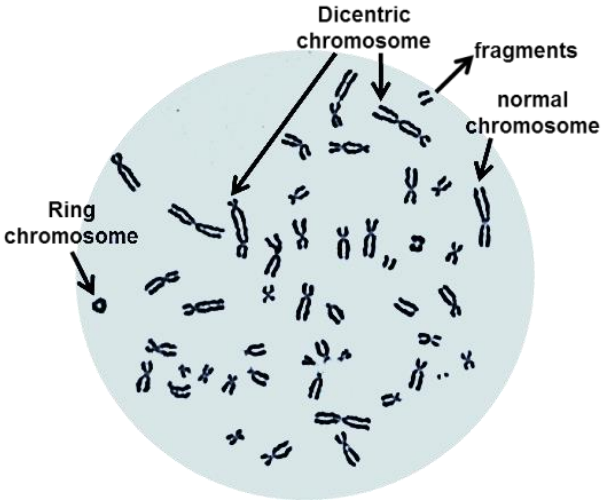
Other methods currently used in cytogenetic dosimetry include the cytokinesis-block micronucleus, the chromosome translocation, and premature chromosome condensation assays. The micronucleus test requires less skill in scoring but also has a more variable background frequency which is known to be dependent on the age and gender of lymphocyte donor. Like dicentrics, micronuclei are unstable aberrations that disappear over time. In addition, many chemicals can induce micronuclei so the assay is not radiation-specific. It is often used as a general toxicological screening test.

The translocation assay is used primarily to estimate dose from historical exposures. Unlike dicentrics and micronuclei, which are eliminated from the peripheral blood over a relatively short time, translocations have been shown to persist for decades. Translocations are detectable by use of a molecular cytogenetic method referred to as chromosome "painting" or fluorescence in situ hybridization (FISH). In numerous studies the frequency of translocations has been shown to be strongly influenced by the age of the lymphocyte donor.

Premature chromosome condensation (PCC) occurs when cells at the interphase stage of the cell cycle are treated to induce the chromosomes to condense prematurely into the familiar shapes of metaphase chromosomes. After the cells are fixed and stained, the chromosomes are examined for fragments which are indicative of chromosome breaks. The PCC assay enables direct observation of radiation-induced damage earlier than is possible when cells must be stimulated to reach mitosis before preparation of

the chromosomes. As shown in Table 15 the PCC assay can detect higher doses than possible with the dicentric assay but the method still requires further validation.

## Dicentric Analysis




Dicentric chromosomes are formed when broken segments of two irradiated chromosomes are mis-repaired forming a chromosome with two or more centromeres. The number of dicentric chromosomes correlates well with the absorbed dose. In the dicentric assay, stimulated lymphocytes are arrested, fixed, and dropped onto glass slides during the metaphase stage of mitosis where the chromosomes are condensed and become visible under the microscope. The images can then be captured electronically and shared over the internet allowing multiple "readers" to analyze the metaphase spreads for the presence of dicentric chromosomes.

Based on calibration curves produced from in vitro exposures, a dose estimate can be made according to the number of dicentrics detected per cell. This assay is generally accepted as the most specific and sensitive method (0.1 Gy) for determining whole-body doses from recent exposures to ionizing radiation (i.e. within days to ~3 months). Additionally, statistical techniques are available that can determine if the body received a homogeneous dose distribution or if the dose was delivered in a non-homogeneous manner in cases where the doses are at or above 2 Gy. The usefulness of this assay is greatly reduced for measuring doses received more than 3 months before the assay because of the half-life (i.e. turnover) of lymphocytes resulting in the instability, and thus loss, of dicentric chromosomes.

Radiation-induced dicentric chromosomes are mechanically unstable during mitosis and are therefore eliminated as the lymphocyte pool is regenerated. In contrast, chromosome translocations are stable during cell division and can be measured using FISH. In this molecular cytogenetic method, fluorochrome-labeled DNA probes that are specific for typically three pairs of chromosomes can be used to detect exchanges by means of fluorescence microscopy. The stability of chromosome translocations has been shown to remain elevated for decades. This method has been used for dosimetry reanalysis of WWII atomic bomb survivors and in civilian radiation accidents that happened decades ago.

## Cytokinesis-Block Micronucleus Assay

The cytokinesis-block micronucleus assay is another method useful in biological dosimetry. In contrast to the direct examination of chromosomes, the micronucleus test is an indirect method to assess chromosome damage and is performed on cells at the interphase stage in the cell cycle. Micronuclei are characterized as small, round-to-oval structures located within the cytoplasm of a cell but physically distinct and separated from the main nucleus. Because they resemble the main nucleus in shape, texture and staining properties, and contain DNA, micronuclei are easily detected as markers of damaged (i.e. broken) chromosomes. The analysis of micronuclei requires less skill, proceeds rapidly, especially with automated slide scanning equipment and typically includes samples of 1,000 cells or more. The test has been improved significantly through the introduction of the cytokinesis-block method and has been shown to be sensitive to doses as low as 0.1 Gy. On the downside, unlike the dicentric assay, age and gender are factors known to affect the background frequency. In vitro studies have demonstrated that a dose of 1 Gy can be estimated with an uncertainty of 0.2 Gy. In vivo studies have shown the lower detection level is about 0.3 Gy.

## Premature Chromosome Condensation

One limitation of assays requiring lymphocyte stimulation is that cells receiving higher radiation doses also experience cell cycle delay and may not reach mitosis. This can result in a large underestimation of the absorbed dose. Chromosomes, however, can be forced to condense prematurely by fusing human lymphocytes with Chinese hamster ovary (CHO) mitotic cells in the presence of polyethylene glycol (PEG).

The PCC assay can also be chemically induced by incubating lymphocytes with a protein phosphatase inhibitor (e.g. okadaic acid), adenosine triphosphate, and a mitosis-promoting factor which avoids the need to maintain cultures of CHO cells. The PCC assay enables direct observation of chromosome damage and earlier than is possible when cells must be stimulated to mitosis. The assay's lower limit of detection is not as low as that of dicentric chromosome assay. It is sensitive to doses higher than detectable with the dicentric chromosome aberration assay.

## Electron Paramagnetic Resonance (EPR)

EPR is sometimes called electron spin resonance (ESR), not to be confused with erythrocyte sedimentation rate. Exposure of humans to ionizing radiation results in radiation-induced changes that can be measured and, depending on the absorbed dose, quantified. The use of EPR for biodosimetry is based on the capability of the technique to provide specific and sensitive measurement of unpaired electrons in solid tissue which are created in proportion to the absorbed dose. The lifetimes of these electrons are very short (nanoseconds) in aqueous systems such as most biological

tissues but can be extremely stable in non-aqueous media, including teeth, bone, fingernails, and hair. EPR has been used for in vitro analyses of extracted teeth to measure doses in populations from Japan and the former Soviet Union. The effectiveness of EPR has been well demonstrated.

## Molecular Markers in Body Fluids and Tissues

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

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

# Section 8 – Delayed Effects

Delayed effects of radiation exposure include radiation-induced carcinogenesis, mental retardation after in utero exposure of offspring, late organ effects (typically vascular changes, fibrosis, atrophy and thyroid dysfunction), cataracts, and infertility.

## Lung Complications

Radiation injury to the lung due to acute exposures is an important, medically difficult aspect of high-dose radiation incidents that may not occur until several months post-exposure. The most radiosensitive subunit of the lung is the alveolar/capillary complex, and early radiation-induced lung injury is often described as diffuse alveolar damage. These complications may arise due to acute doses to the lungs in excess of 6-8 Gy. Reactive oxygen species (ROS) generated by radiation damage are directly toxic to lung cells and initiate a cascade of molecular events that alter the cytokine milieu of the microenvironment, creating a self-sustaining cycle of inflammation and chronic oxidative stress. A variety of cytokines have been implicated as indicators/mediators of lung injury.

Replacement of normal lung parenchyma by fibrosis is generally the culminating event. Depending on the dose/dose rate and volume of lung irradiated, acute radiation pneumonitis may develop, characterized by dry cough and dyspnea. Fibrosis of the lung, which causes further dyspnea, is a possible late complication.

## Studies on Long-Term Effects of Radiation

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

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

## Cancer Risk

Medical personnel at all levels of care must understand the psychological distress that patients experience regarding delayed effects of radiation exposure. Based on data available from the American Cancer Society (US Mortality, 2006 http://www.cancer.org/docroot/stt/stt_0.asp?from=fast, 2009 presentation), it is expected that in the US, cancer is the cause of death in 23.1% of the population.

Understanding excess risk of fatal cancer requires general knowledge of baseline risk of fatal cancer. From above, in a population of ten million people, 2.31 million people are expected to die from cancer. According to NCRP Report No. 115 (1993), the lifetime excess risk of fatal cancer is 4% per Sv (0.04% per rem) for a worker population and 5% per Sv (0.05% per rem) for the general population. If this same population received an excess total dose of 0.1 Sv (10 rem) over their life span, there would be an excess risk of 50,000 cancer deaths {calculated from (10,000,000 people) x (0.0005 deaths per person per rem) x (10 rem) = 50,000 excess cancer deaths}. Therefore, the total revised burden of fatal cancers in a population of ten million individuals from a 0.1 Sv (10 rem) exposure is increased from 2.31 million to 2.36 million.

A similar magnitude of increase in overall cancer risk demands an understanding of baseline cancer risk. Again, the excess lifetime risk of developing cancer is extremely small. According to estimates of the American Cancer Society, one out of every two men and one out of every three women will develop cancer. This equates to about 42% of the whole population as developing cancer within their lifetime. BEIR VII estimates that that 43 out of every 100 people in the US will be diagnosed with cancer in their lifetime. It additionally estimates that approximately one cancer per 100 people (~1%) may result from a single exposure to 10 rem (0.1 Sv) above background, implying that the radiation-induced cancer rate is about 10% per Sv.

The reader should note that risk estimates among various Federal agencies, advisory groups, and international committees vary a bit (BEIR V and VII, IAEA, NCRP, EPA, UNSCEAR, etc.), but all are generally in the ranges discussed above.

Resources that may be helpful in medical consultation with irradiated patients include:

- The Health Physics Society website: *Ask the Experts* (https://hps.org/publicinformation/ate/)
- BEIR V, VII and UNSCEAR 1988, 2000 reports
- Various reports of the NCRP and ICRP such as NCRP 115, and ICRP 60 and 103
- The American Cancer Society website (http://www.cancer.org/research/index)

## Non-Cancer Effects

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

Radiation-induced cataracts are well documented, most notably present as posterior subcapsular cataracts. Senile or age-related cataracts are nuclear in position. Neutrons are particularly effective in causing cataract formation. The threshold dose for cataract formation is approximately 0.5 Gy (greater with fractionated doses). At 40 Gy dose to the eye, approximately 100% will form cataracts. The latency period ranges from 2 months to 35 years. In general, with increased dose to the eye, the latency period decreases.

## Radiation and Pregnancy

Pregnancy causes concerns about possible fetal effects from radiation exposure. The gestational age of a fetus is calculated from the beginning of the last menstrual (LMP) and averages 280 days, divided into three trimesters. During the first two weeks

following ovulation, successive biological events include fertilization, formation of the free blastocyst, transit down the fallopian tube and implantation. No statistically significant effects have been noted for medically significant irradiation before conception.

If irradiation occurs during transit of the blastocyst down the fallopian tube, an "all or none" effect is generally noted. If implantation is successful, the pregnancy generally has a successful outcome. During the first trimester period of organogenesis, the embryo is sensitive to growth-retarding effects because of the criticality of cellular activities and the high proportion of radiosensitive cells.

For uterine doses > 0.5 Gy, growth retardation, gross congenital malformations, and microcephaly have been the predominant effects. Interestingly, there has been no report of external irradiation inducing morphologic malformation in a fetus unless it also exhibits growth retardation or a CNS anomaly.

The highest risk of mental retardation is irradiation of the fetus during the period of major neuronal migration (8-15 weeks) and the incidence is dose dependent. At 1 Gy fetal dose, approximately 75% will experience mental retardation. Conversely, at 16-25 weeks gestation, the fetus shows no increase in mental retardation at fetal doses <0.5 Gy.

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

# Section 9 – Psychological Support and Risk

The importance of early recognition of signs of stress or other psychological issues cannot be overstated. Therefore, early involvement of mental health professionals, clergy, etc., should be considered. Since risk is such a personal concept, it may be difficult to deal with the anxieties in a population associated with a real or imagined radiological incident. One has to keep in mind that many sources misrepresent the hazards associated with radiation.

According to *The Medical Basis for Radiation-Accident Preparedness III, The Psychological Perspective* (Ricks, et.al., 1990), simply conveying information is not enough. Successful communication regarding radiation incidents is multi-faceted, and some issues have been addressed inadequately. For instance:

- The media is often seen as covering viewpoints, not truth.
- To a scientist, objectivity means adhering to evidence in the search for the truth. To a journalist it may simply mean balance.
- Politics seems to be more newsworthy than science.
- Claims of risk seem to get more press than claims of safety.

Moreover, the professional news media is not the only source of images that shape our opinions. Comic books and fictional television programs link radiation exposure and radioactive contamination to "glowing in the dark," immediate and severe "radiation sickness" after exposure to radiation, mutations leading to multiple extra body parts, genetic effects leading to deformed offspring and other bizarre physical and functional abnormalities. These images mislead the public regarding the essential nature of radiation and its risk.

## Fear and the Immediate Psychological Response

Authorities should "alert people when they ought to be alerted and reassure them when they ought to be reassured." (Sandman, Explaining Environmental Risk, 1986). Public anxiety and fear associated with radiation emergencies is often out of proportion to the degree of radiation-induced health effects (IAEA, 2005). Symptoms of radiation illness in just a few uninformed people can produce devastating psychological effects on an entire community or group of responders/care providers. Acute anxiety may develop that in turn, leads to emotional stress and poor performance.

Care should be taken to avoid unnecessary stressors. The IAEA recommends that it may be beneficial to make available educational materials and dedicated counselors at receiving centers, taking care to adjust for religious, cultural and social customs while providing care such as surveying/decontaminating patients and separating family members. It has been the experience at REAC/TS that anxiety frequently results in prodromal symptoms of ARS such as nausea and even vomiting. It is important for responders to appreciate that victims may have fear that generates these clinical symptoms.

## Long-Term Psychological Effects

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

Affected individuals appear to fall into one of three groups:

- Those who are distressed
- Those who exhibit behavioral changes
- Those with a high risk to develop psychiatric illness

Common reactions may manifest as sadness, anger, fear, difficulty sleeping, impaired ability to concentrate, and disbelief, or as nonspecific somatic complaints. This condition is often referred to as Multiple Idiopathic Physical Symptoms (MIPS).

Outcomes vary widely. Most individuals improve over time but some may develop long-term psychosocial needs. Physicians and psychologists must remember that after a radiation exposure, people with no prior history of psychosocial dysfunction are vulnerable to psychiatric illness. No only victims but also healthcare providers, including first responders in the field, first receivers in the hospital and other caregivers may develop psychosocial dysfunction.

## Treatment

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

The unique psychological consequences of a mass casualty, radiation incident requires the availability of Psychological First Aid (PFA) to facilitate coping with stress, depression and other severe emotional and physical reactions that may occur. PFA includes active engagement with people exhibiting spontaneous crying, emotional lability, confusion, increased anxiety, a sense of helplessness and other signs of a failed ability to cope with losses. Establishment of trust is essential, using open communication of accurate information, active listening and demonstration of respect. Tools include the use of a soft tone of voice, simple questions and open posture. PFA is aimed at providing safety, calmness, connectedness (keeping families and friends together) and self-efficacy (empowerment of survivors with practical suggestions). When referrals are necessary, help should be secured by directing people to available services.

While initial radiation dose estimations may be available fairly quickly, it is common for some time to elapse before final results are available. During this time period

ensuring consensus among experts, and thus a common message, can help to allay patient fear and anger.

## Impacts on Healthcare Providers and Responders

Minimizing loss of life requires coordinated collaborative efforts of hazardous materials (HAZMAT) teams, civil support and other state teams, regional and federal response teams and others that will conduct first and early response activities, including transportation to clinical reception/collection areas for radiological assessment and triage, and to area hospitals for medical management. A large volume or mass casualty radiological incident will have major effects on healthcare systems, as hospital and emergency department workers will become first receivers and provide the majority of medical care to surviving victims. An incident command system designed to coordinate command and control will be developed at hospitals that will impose an unfamiliar reporting system on healthcare providers. Individually and collectively, these events will create stress, anxiety and personal hardships for responders and healthcare providers. Responders to the Goiânia accident illustrate the impact of investigating and managing a large volume of victims.

On September 30, 1987, in Goiânia, Brazil, a large-scale radiological incident occurred as a result of individuals removing a $^{137}Cs$ radiotherapy device from an abandoned clinic and breaching the source capsule. The individuals were unaware of the radiation/contamination hazards. It was about 2.5 weeks before the radiological implications of the incident were discovered and it resulted in the deaths of four people. More information can be found in the IAEA report *The Radiological Accident in Goiânia* (http://www-pub.iaea.org/MTCD/publications/PDF/Pub815_web.pdf).

The greatest impact was seen on those responders who worked within the first 2 months of the incident performing surveys, triaging patients and providing medical care. Virtually all of these workers reported psychosocial symptoms that included guilt, pity and a sense of helplessness, compared to those who worked months 4-5, where only 50 % of workers reported these feelings.

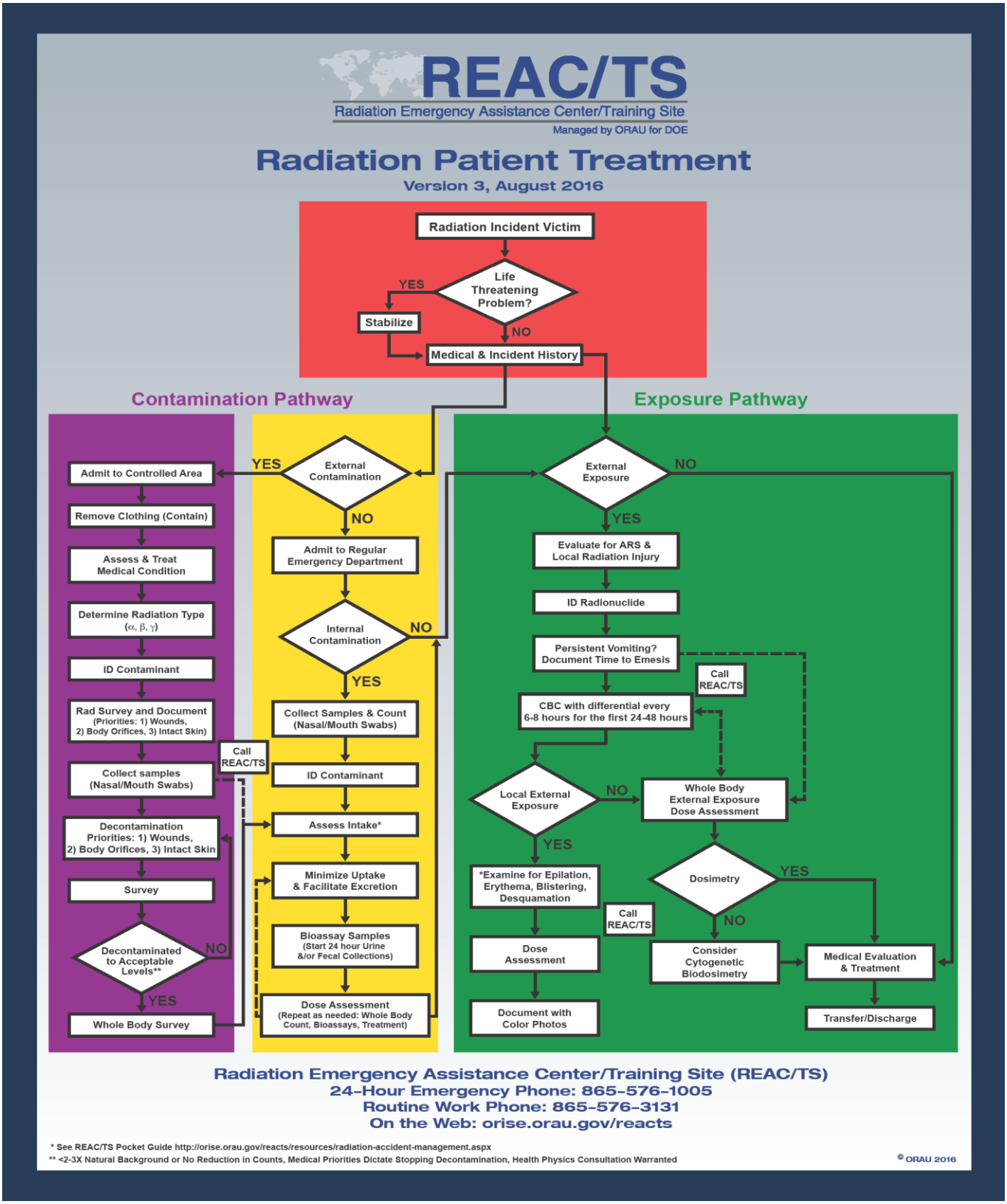
The working conditions of the early responders had a significant impact on the psychological toll. They worked 12-15 hours per day in unfamiliar and uncomfortable conditions (radioactive contamination, necessary protective clothing, etc.). Temperatures were as high as $100^{O}$ F. The population's apprehension, and outright fear, sometimes resulted in unexpected confrontations. And, as can be expected, the chaotic nature of the early phases of a large-scale emergency response exacerbated the problems (Ricks, et al., 1990).

Many of the responders reported they noticed behavioral changes in their coworkers such as increased alcohol use and aggressive behavior. Other signs of stress may also be seen. These behavioral issues in responders should be approached in the same manner as recommended to manage psychosocial issues in patients:

- Provision of psychological first aid (PFA) to establish trust and facilitate coping with the situation.
- Encourage the workers to talk about their stress (decompression). It may be eased through catharsis.
- Pay attention to behavior changes and try to understand the underlying reasons.
- Provide assistance to team leaders when they are making decisions regarding work assignments to help ensure the person assigned is right for the job and that the work (and radiation dose) is being equally and fairly distributed.
- Consider providing pre-assignment personality and psychological evaluation.

# Appendix A – Supplemental Information

## REAC/TS Patient Treatment Algorithm



## Table 16 – Approximate Skin Injury Thresholds vs. Acute Doses

| Approx. Dose | Predicted Effect | Time Post Exposure* |
|---|---|---|
| 300 rads (3 Gy) | Epilation | 2-4 weeks |
| 600 rads (6 Gy) | Erythema | Early, then 2-4 weeks later |
| 1000-1500 rads (10-15 Gy) | Dry Desquamation | 2-4 Weeks |
| 1500-2500 rads (15-25 Gy) | Wet Desquamation | 2-4 Weeks |
| > 2500 rads (> 25 Gy) | Deep Ulceration/Necrosis | Dependent upon dose |

* At higher doses the time to onset of signs/symptoms may be compressed.

## Table 17 – Approximate Thresholds for Acute Radiation Syndromes

| Dose | Syndrome | Potential Signs/Symptoms* |
|---|---|---|
| 0-100 rads (0-1 Gy) | NA | Generally asymptomatic, potential slight drop in lymphocytes later (near 1 Gy) |
| ≥ 100 rads (≥ 1 Gy) | Hematopoietic | Anorexia, nausea, vomiting, initial granulocytosis and lymphocytopenia |
| ≥ 600 rads (≥ 6 Gy) | Gastrointestinal | Early severe nausea, vomiting, watery diarrhea, pancytopenia |
| ≥ 800 rads (≥ 8 Gy) | Neurovascular | Nausea/vomiting within first hour, prostration, ataxia, confusion |

* At higher doses the time to onset of signs/symptoms may be compressed.

## Table 18 – Dose Conversion Factors

**Approximate dose rates to the skin for 1 MBq in a sealed source - PHITS Simulations**

| | | *Dose to first 0.07mm* | | | *Dose to first 1mm* | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Nuclide | Gamma Constant (mSv-cm²/hr-MBq) | Dose Rate Photon Only (mSv/h) | Dose Rate due to secondary electron buildup in encapsulation (mSv/h) | Dose Rate Total (mSv/h) | Dose Rate Photon Only (mSv/h) | Dose Rate due to secondary electron buildup in encapsulation (mSv/h) | Dose Rate Total (mSv/h) | Dose rate at 1cm tissue depth (mSv/h) | Dose rate at 3cm tissue depth (mSv/h) |
| Cs-137 | 0.927 | 0.95 | 3.99 | 4.94 | 2.90 | 1.28 | 4.18 | 0.48 | 0.065 |
| Co-60 | 3.48 | 1.60 | 14.00 | 15.60 | 5.42 | 8.20 | 13.62 | 1.74 | 0.262 |
| Ir-192 | 1.24 | 2.65 | 6.80 | 9.45 | 5.12 | 1.04 | 6.16 | 0.59 | 0.092 |
| Ra-226 | 2.23* | 2.15 | 11.30 | 13.45 | 5.30 | 4.80 | 10.10 | 1.28 | 0.157 |
| Se-75 | 0.548 | 1.95 | 4.61 | 6.56 | 2.43 | 0.47 | 2.90 | 0.21 | 0.022 |

- 0.7 and 1 mm data from *Improved Contact Dose Rate Conversion Factors and Secondary Electron Correction Factors for Encapsulated Gamma Sources*: Presented by Ed Waller on 07/12/17 - Raleigh, NC - Health Physics Society Annual Meeting - Session WAM-A.10 (Primary Author: Eric Heritage, University of Ontario Institute of Technology)
- 1 cm and 3 cm data was provided by Ed Waller on 03/02/2016 via personal correspondence.
- Cs, Co, Ir, Ra 1 cm and 3 cm data closely resembles that published in NCRP 40.
- No data available in NCRP 40 for Se.
- Gamma constant information from *Exposure Rate Constants and Lead Shielding Values for Over 1,100 Radionuclides* (Smith, Stabin – Health Physics – 2012) – converted from conventional US units listed in the reference
- * Converted from NCRP 40 (includes daughter contributions)

**Note: Multiply mSv/hr/MBq by 3.7 to get R/hr/mCi**

Table data compiled by Steve Sugarman

**Table 19 – Standard Prefixes for Units of Measurements**

| Multiple | Prefix | Symbol |
|---|---|---|
| $10^{18}$ | exa | E |
| $10^{15}$ | peta | P |
| $10^{12}$ | tera | T |
| $10^{9}$ | giga | G |
| $10^{6}$ | mega | M |
| $10^{3}$ | kilo | k |
| $10^{2}$ | hecto | h |
| $10^{1}$ | deka | da |
| $10^{-1}$ | deci | d |
| $10^{-2}$ | centi | c |
| $10^{-3}$ | milli | m |
| $10^{-6}$ | micro | μ |
| $10^{-9}$ | nano | n |
| $10^{-12}$ | pico | p |
| $10^{-15}$ | femto | f |
| $10^{-18}$ | atto | a |

**Table 20 – Activity Conversions**

| | | | |
|---|---|---|---|
| 1 terabecquerel | 1 TBq | 27 curies | 5.99E13 dpm |
| 1 gigabecquerel | 1 GBq | 27 millicuries | 5.99E10 dpm |
| 1 megabecquerel | 1 MBq | 27 microcuries | 5.99E7 dpm |
| 1 kilobecquerel | 1 kBq | 27 nanocuries | 5.99E4 dpm |
| 1 becquerel | 1 Bq | 27 picocuries | 5.99E1 dpm |
| 1 kilocurie | 1 kCi | 37 terabecquerels | 2.22E15 dpm |
| 1 curie | 1 Ci | 37 gigabecquerels | 2.22E12 dpm |
| 1 millicurie | 1 mCi | 37 megabecquerels | 2.22E9 dpm |
| 1 microcurie | 1 μCi | 37 kilobecquerels | 2.22E6 dpm |
| 1 nanocurie | 1 nCi | 37 becquerels | 2.22E3 dpm |

**Table 21 – Dose Equivalent/Equivalent Dose Conversions**

| | | |
|---|---|---|
| 1 sievert | 1 Sv | 100 rem |
| 1 millisievert | 1 mSv | 100 millirem |
| 1 microsievert | 1 μSv | 100 microrem |
| 1 rem | 1 rem | 10 millisieverts |
| 1 millirem | 1 mrem | 10 microsieverts |
| 1 microrem | 1 μrem | 10 nanosieverts |

**Table 22 – Absorbed Dose Conversions**

| | | |
|---|---|---|
| 1 gray | 1 Gy | 100 rads |
| 1 milligray | 1 mGy | 100 millirad |
| 1 microgray | 1 μGy | 100 microrad |
| 1 rad | 1 rad | 10 milligrays |
| 1 millirad | 1 mrad | 10 micrograys |
| 1 microrad | 1 μrad | 10 nanograys |

**Table 23 – Acronyms**

| | |
|---|---|
| ALC | absolute lymphocyte count |
| ALI | annual limit on intake |
| ANC | absolute neutrophil count |
| ARS | acute radiation syndrome |
| BAT | Biodosimetry Assessment Tool |
| BEIR | Biological Effects of Ionizing Radiation |
| Bq | becquerel |
| CBC | complete blood count |
| Ci | curie |
| CLL | chronic lymphocytic leukemia |
| CPM | counts per minute |
| CRP | C-reactive protein |
| CSF | colony-stimulating factor |
| DPM | disintegrations per minute |
| DRD | direct read-out dosimeter |
| DTPA | diethylenetriaminepentaacetic acid |
| DU | depleted uranium |
| EDTA | ethylenediaminetetraacetate |
| FDA | Food and Drug Administration |
| FISH | fluorescent in-situ hybridization |
| G-CSF | granulocyte colony-stimulating factor |
| GI | gastrointestinal |
| G-M | Geiger-Mueller |
| GM-CSF | granulocyte-macrophage colony-stimulating factor |
| Gy | gray |
| ICRP | International Commission on Radiation Protection |
| IDSA | Infectious Disease Society of America |
| IND | Improvised nuclear device |
| KI | potassium iodide |
| LD | lethal dose |

| | |
|---|---|
| NCRP | National Council on Radiation Protection and Measurements |
| PCC | premature chromosome condensation |
| QD | every day |
| QF | quality factor |
| RDD | radiation dispersal device |
| REAC/TS | Radiation Emergency Assistance Center/Training Site |
| s.c. | subcutaneous |
| Sv | sievert |
| UNSCEAR | United Nations Scientific Committee on the Effects of Atomic Radiation |
| WBC | white blood count (sometimes whole body count) |

# Appendix B - Additional Response Resources

- **DOE – National Nuclear Security Administration – NNSA – https://nnsa.energy.gov/:** The National Nuclear Security Administration (NNSA) ensures that capabilities are in place to respond to any NNSA or Department of Energy (DOE) facility emergency. It is also the nation's premier responder to any nuclear or radiological incident within the United States or abroad and provides operational planning and training to counter both domestic and international nuclear terrorism. https://nnsa.energy.gov/
- **Armed Forces Radiobiology Research Institute – AFRRI – *https://www.usuhs.edu/afrri/*:** The AFRRI mission is to preserve the health and performance of U.S. military personnel and to protect humankind through research that advances the understanding of the effects of ionizing radiation. To these ends, the institute collaborates with other government facilities, academic institutions, and civilian laboratories in the United States and other countries to research the biological effects of ionizing radiation. In addition, it provides medical training and emergency response to manage incidents related to radiation exposure. A similar pocket guide (*Medical Management of Radiological Casualties, 3rd Edition, 2009*) was produced by AFRRI to help guide military medical operations.
- **International Atomic Energy Agency (IAEA) – IAEA's Response System – http://www-ns.iaea.org/tech-areas/emergency/iaea-response-system.asp:** The prime objectives of the IAEA's Response System is to facilitate the (1) exchange of official real-time information among States/relevant international organizations; (2) provision of assistance/advice to States/relevant international organizations upon request; and (3) provision of relevant, timely, truthful, consistent and appropriate public information. REAC/TS is a member of the IAEA Response Assistance Network (RANET). https://www.iaea.org/
- **World Health Organization (WHO) – Radiation Emergency Medical Preparedness and Assistance Network (REMPAN):** The network is designated to provide emergency medical and public health assistance to people over-exposed to radiation. It also facilitates a long-term care and follow-up of radiation accident victims and conducts research in radiation emergency medicine, radiotherapeutics, bio-dosimetry and radiation epidemiology. REAC/TS is a WHO/REMPAN collaboration center. http://www.who.int/ionizing_radiation/a_e/rempan/en/
- **Center for Disease Control and Prevention (CDC), Emergency Preparedness and Response : A** government website intended to increase the nation's ability to prepare for and respond to public health emergencies, including radiological incidents. http://emergency.cdc.gov/radiation/

# Appendix C – Selected References, Reports and Websites

- Communication with the Public in a Nuclear or Radiological Emergency – http://www-pub.iaea.org/books/IAEABooks/8889/Communication-with-the-Public-in-a-Nuclear-or-Radiological-Emergency
- Generic Procedures for Medical Response During a Nuclear or Radiological Emergency – http://www-pub.iaea.org/MTCD/publications/PDF/EPR-MEDICAL-2005_web.pdf
- NCRP Report 128 – Radionuclide Exposure to the Embryo/Fetus (1998)
- NCRP Report 138 – Management of Terrorist Events Involving Radioactive Material (2001)
- NCRP Report 160 – Ionizing Radiation Exposure of the Population of the United States (2009)
- NCRP Report 161 – Management of Persons Contaminated with Radionuclides: Handbook (2008)
- NCRP Report 165 - Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers (2010)
- NCRP Report 166 - Population Monitoring and Radionuclide Decorporation Following a Radiological or Nuclear Incident (2010)
- NCRP Report 174 – Preconception and Prenatal Radiation Exposure: Health Effects and Protective Guidance(2013)
- Rapid Internal and External Dose Estimation – http://orise.orau.gov/files/reacts/rapid-internal-external-dose-magnitude-estimation.pdf
- Radiation Emergency Assistance Center/Training Site (REAC/TS) – http://www.orise.orau.gov/reacts
- USG DHHS Radiation Event Medical Management – REMM – http://www.remm.nlm.gov/