Radiological Terrorism: A Primer

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Chapter 1: Radiological Fundamentals

The word "radiation" usually refers to ionizing radiation – radiation with enough energy to create ion pairs in matter. Ultraviolet light can do this, as can x-rays, gamma rays, and other kinds of radiation. Visible light is also radiation, but it is not energetic enough to cause ionizations, so it cannot normally cause problems. By comparison, ionizing radiation can damage our DNA, causing health effects in sufficiently high doses.

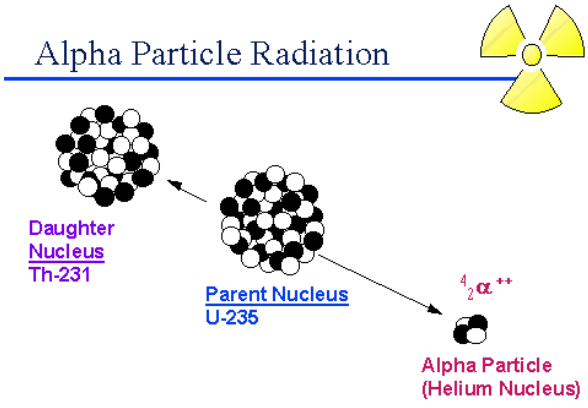
It's important to distinguish between radiation and radioactive contamination. Radiation is energy emitted by atoms that are unstable. Radiation travels through space to some extent – some kinds of radiation can only travel a few millimeters, while other types can travel for many meters. Radioactive contamination is the presence of radiation-emitting substances (radioactive materials, or RAM) in a place where is not desired. A patient may be contaminated with radioactive materials, but that patient will not be radioactive.

Types of radiation

There are three basic kinds of radiation that medical staff can expect to see; alpha, beta, and gamma radiation. These have distinct properties, which are summarized in the table below.

➢ *Alpha radiation*

Alpha radiation is emitted by heavy atoms, such as uranium, radium, radon, and plutonium (to name a few). Alpha particles are helium nuclei, making them the most massive kind of radiation. Alpha radiation can cause a great deal of damage to living cells it encounters, but has such a short range in tissue (only a few microns) that external alpha radiation cannot penetrate the dead cells of the epidermis to irradiate the living cells beneath. However, if inhaled, swallowed, or introduced into open wounds, alpha radiation can be very damaging. In nature, alpha radiation is found in rocks and soils as part of the minerals, in air as radon gas, and dissolved in water as radium, uranium, or radon. Alpha emitters are also found in nuclear power plants, nuclear weapons, some luminous paints (radium is used for this), smoke detectors, and some consumer products. Objects and patients exposed to alpha radiation may become contaminated, but they do not become radioactive.



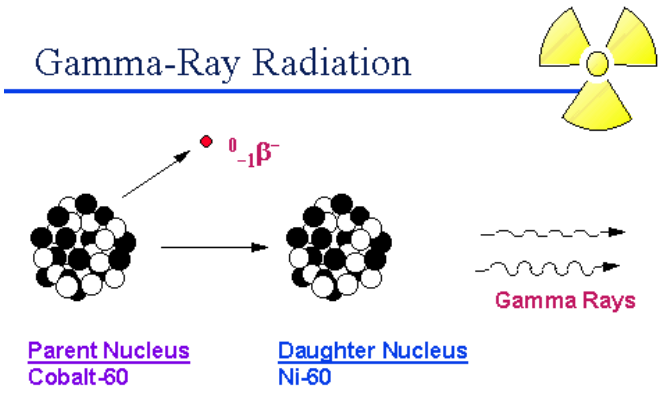
➢ *Beta radiation*

Beta particles are electrons and are both lighter than alpha particles and posses a lower electrical charge. This means that they are not nearly as damaging, although they will penetrate up to a centimeter into tissue. Beta particles will give radiation dose only to the skin, unless they are ingested, inhaled, or enter the body through open cuts or wounds. In nature, beta radiation is

found as part of natural potassium, in rocks and soils, and in the atmosphere as naturally produced carbon 14 and tritium. Beta-emitting radioactive materials are used in research, some luminous paints, and for both diagnostic and therapeutic medical purposes. Objects and patients exposed to beta radiation may become contaminated, but they do not become radioactive.

➢ *Gamma radiation*

Gamma rays are energetic photons, similar to x-rays. Gamma radiation is much less damaging than alpha radiation and is about as damaging as beta radiation. Unlike alpha and beta radiation, gamma radiation will penetrate the whole body (as x-rays will), so it will deliver radiation dose to internal organs as well as to the skin. In nature, gamma radiation is ubiquitous and is found in outer space and on the surface of the earth. Gamma radioactivity is found in rocks and soils as well as in naturally radioactive isotopes of potassium found in foods and our own bodies. Gamma radiation is used for many research, industrial, and medical purposes. Objects and patients exposed to gamma radiation may become contaminated, but they do not become radioactive.



➢ *Neutron radiation*

Neutrons are one of the major particles in an atomic nucleus, and they are released by nuclear reactions such as atomic fission or fusion. They are also found naturally in cosmic radiation. Neutrons have a mass of 1 atomic mass unit and no electrical charge, so they can penetrate to all parts of the body, and they do more damage than all except alpha radiation. Objects or patients exposed to neutron radiation may become slightly radioactive, but this level of radioactivity poses no risk to medical or emergency response personnel; the amount of neutron radiation required to cause a person to become dangerously radioactive will kill a patient almost immediately.

Type	**Mass**	**Charge**	**Penetrating Ability**	**Relative Damage**	**Shielding**
Alpha (α)	4	+2	Very low (~5 microns in tissue)	20	skin, paper
Beta (β)	0.0005	±1	Low (up to 1 cm in tissue)	1	clothing, plastic
Gamma (γ)	0	0	High (penetrates whole body)	1	lead, water
Neutron (n)	1	0	High (penetrates whole body)	3-10	Plastic, water

Properties for major kinds of radiation

Background radiation exposure

We are all exposed to radiation on a daily basis from both natural and man-made sources. Background radiation levels vary widely depending on altitude, local geology, and latitude, but average background radiation dose in the US and Canada is about 360 milli-rem (mrem) annually. Of this, nearly 300 mrem is due to natural radiation and the remainder is from artificial sources.

There are trace amounts of radioactivity in rocks and soils, in our bodies, and in the air we breathe, and charged particles from the sun and our galaxy bombard our planet continually. This background radiation exposure is unavoidable, but our biochemistry is able to repair the resulting DNA damage. Each year, we are exposed to about 200 mrem from radon inhalation, 28 mrem from uranium, thorium and potassium in rocks and soils, and 27 mrem from cosmic radiation. To this, we can add another 40 mrem annually from the 0.01% of potassium in our bodies that is naturally radioactive for a total of about 295 mrem/yr from natural radiation. In some places, such as Ramsar Iran and Kerala India, residents are exposed to radiation levels nearly 100 times as high, without apparent ill effects.

Man-made sources of radiation account for about 65 mrem/yr for US residents. Exposure to medical radiation yields an average dose of 53 mrem/yr, although this varies considerably depending on a person's actual medical history. Consumer products expose us to about 10 mrem/yr, and all other sources of man-made radiation contribute another 2 mrem/yr to our average radiation exposure. Artificial sources of radiation account for about 16% of total radiation exposure.

In all, we receive about 360 mrem/yr from background sources of radiation; a dose that varies considerably in both directions depending on local geology, elevation, and other factors. It is worth noting that, even in areas with exceptionally high levels of natural radiation, inhabitants do not appear to suffer from any ill effects. This suggests that occupational exposure to moderately elevated radiation levels is not harmful.

Source	**Annual radiation dose (mrem/yr)**
Radon	200
Biochemistry	40
Geologic materials	28
Cosmic radiation	27
Medical sources	53
Consumer products	10
Other	2
Total	360

Background radiation doses from natural and man-made causes

Chapter 2: Biological effects of radiation exposure

Many people are understandably concerned about the health effects of exposure to radiation and radioactive contamination. There are two distinct types of radiation exposure, acute and chronic, and two primary exposure modes, irradiation (i.e. exposure to radiation) and radioactive contamination. Each exposure type and mode is slightly different and must be treated differently by medical staff. In addition, there are concerns about the reproductive effects of radiation exposure. In this section, these concerns will be discussed.

Risk to emergency responders and medical staff from contaminated or irradiated patients
Patients involved in radiological incidents, including acts of radiological or nuclear terrorism, may be heavily contaminated and may have been irradiated. It is only natural to worry about the health effects from caring for such patients. This worry must be addressed; experience with genuine radiological incidents as well as drills has shown that medical personnel consistently, and unnecessarily delay or deny treatment to radiological patients, often leading to unnecessary complications, suffering, and even death.

Medical staff must not delay or deny medical care to radiological patients. With very few exceptions, radiological patients pose no health risk to medical care-givers, provided reasonable precautions are taken. These precautions include universal precautions to minimize the chance of contamination, wearing microbe-filtering masks (such as the N-95 mask) to reduce the chance of inhaling radioactive particles, and wearing personal protective equipment (e.g. shoe covers, gloves, and a lab coat or the equivalent) while caring for radiological patients. These precautions are described in more detail later in this primer. The rest of this chapter will primarily discuss the health effects of radiation exposure to which patients may have been exposed.

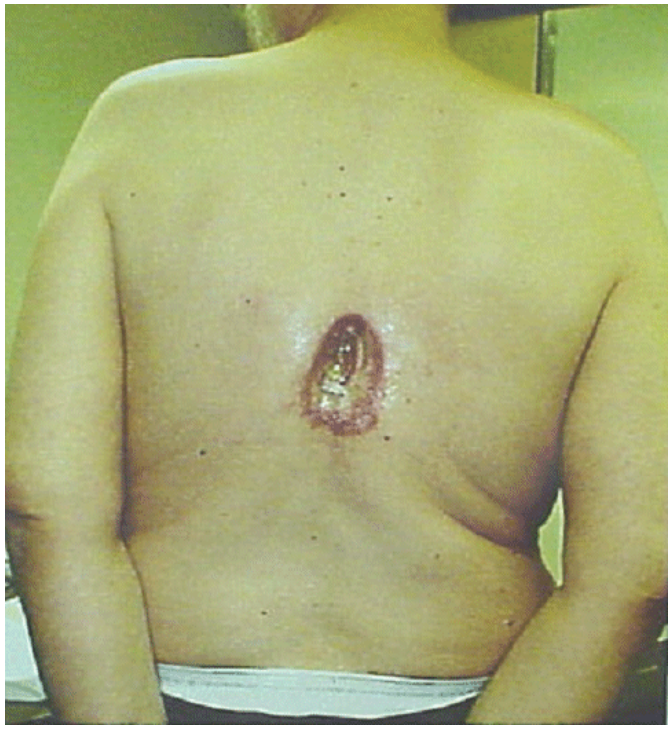
Acute exposure to high doses of radiation

Exposing the whole body to very high levels of radiation in a short period of time can be harmful or fatal to the patient. Exposing parts of the whole body to very high radiation levels can also cause harm, but is usually not life-threatening. Acute radiation injury has been noted in the survivors of the Japanese atomic bombings, among surviving Chernobyl workers, in the wake of nuclear criticality accidents, and among people who have found lost radioactive sources with high levels of activity. Acute radiation injury to limited parts of the body has also been noted in patients receiving excessive fluoroscopy, mineralogists misusing x-ray diffraction equipment, industrial employees using linear accelerators, and radiation oncology patients. Acute exposure to high levels of radiation can lead to deterministic radiation effects, which are effects that will occur after a threshold dose is exceeded. Examples of deterministic effects include skin burns (erythema), nausea, and so forth.

Sunburn is a mild form of acute exposure to radiation, but it serves as a starting point to acute radiation injury. At a skin dose of a few hundred rem, the patient will exhibit erythema and, at higher doses, blistering and peeling (dry and moist desquamation). Depending on the characteristics of the exposure, one side of the body may be more affected – typically the side facing the radiation source. Very high radiation doses to parts of the body will produce these same symptoms to limited parts of the body. The accompanying photos show the effects of radiation burns to the back (from a radiology procedure) and to the hands (in an atomic bomb

survivor). Some patients may exhibit symptoms of both limited and whole-body radiation exposure. These are typically patients who come across abandoned radioactive sources and carry them home (see the case study on the Georgian woodsmen). Other effects of acute whole-body radiation exposure can include depilation, nausea, and a variety of radiation syndromes that are described below.





Radiation injury photos from the Nagasaki bomb (left) and excessive fluoroscopy (right).

- ***Prodromal syndrome***

In some cases, radiation effects may appear within a few hours of radiation exposure and will persist for up to a few days. In general, higher doses result in earlier and more severe symptoms. At lower levels of exposure, symptoms may include fatigue, nausea, and vomiting. At higher (and probably lethal) exposure levels, patients will also experience fever, diarrhea, and hypotension. Patients with prodromal syndrome have likely been exposed to at least 100 rem, but symptoms will appear at any higher level of exposure. Patients exhibiting symptoms within 30 minutes of exposure have likely received a lethal dose of radiation, as have patients experiencing immediate diarrhea.

- ***Hematopoeitic syndrome***

The blood-forming organs are among the most sensitive to the effects of radiation, so these organs are among the first to show the results of high radiation exposure. Hematopoietic syndrome begins to appear at doses of from 300 to 800 rem, when the precursor cells are sterilized or killed. This leads to a reduction in blood cell counts as older cells die and are not replaced, and it leaves the patient open to infection and other related problems. Following the initial prodromal syndrome, a patient may be relatively free of symptoms for some time, although a great deal is occurring. Patients with lower levels of exposure may recover from their exposure if the bone marrow can regenerate and if the patient receives medical support (typically antibiotic treatment). At higher levels of exposure, the patient will begin to exhibit chills, fatigue, hair loss, petechia, and ulceration of the mouth as well as infection, bleeding, immune

system depression, and other symptoms resulting from the loss of blood cells. A dose of about 300 to 400 rem is lethal to 50% of the population (called the LD_{50} dose) without medical support. With medical support, the LD_{50} dose is about 700 to 800 rem.

- ***Gastrointestinal syndrome***

Patients exposed to 1000 rem (10 Gy) or more will lead to gastrointestinal syndrome and, most likely, death within 3-10 days of exposure. Radiation exposures in this range sterilizes dividing crypt cells, leading to loss of cells from the villi. Within a few days, the villi become almost totally flat as the outer surface sloughs off and is not replaced. In one particular case (a man exposed to between 1100 and 2000 rem in 1946) the patient remained in relatively good condition for nearly a week, at which time he began suffering bloody diarrhea, circulatory collapse, and severe damage to the epithelial surfaces throughout the intestinal tract.

- ***Cerebrovascular syndrome***

Exposure to exceptionally high doses of radiation (in excess of 10,000 rem or 100 Gy) will result in damage to the central nervous system, normally among the most radiation-resistant parts of the body. Cebrovascular syndrome is accompanied by symptoms of all other radiation syndromes, and it usually results in death within several hours to a few days of exposure. Patients exposed to such high levels of radiation will experience almost immediate nausea, vomiting, disorientation, seizures, and other symptoms of neurological distress, followed by coma and death. Although the exact cause of death is not known, it is thought that part of the cause is the buildup of cranial pressure due to leakage of fluid from blood vessels.

Effects of acute radiation exposure

Dose (REM)	**Syndrome or effect ***	**Comments**
~1	Chromosome changes	Increase in dicentric chromosomes and chromosome fragments noted
15	Temporary spermatic changes	Possible temporary (up to several months) sterility
25	Blood cell changes	Begin to see depression in red and white blood cells
100	Radiation sickness	Mild at lower doses, severity and rapidity of onset increases rapidly with increasing dose
300-800	Hematopoeitic syndrome	Changes in blood cell count due to damage to crypt cells, severe radiation sickness, recovery possible with medical support
400	LD_{50}	With medical treatment, LD50 is about 800 rem
1000	GI syndrome, LD_{100}	Relatively rapid onset for vomiting
2000+	Radiation dermatitis	Skin breakdown in 2 weeks or less
10,000	Cerebrovascular syndrome	Rapid incapacitation, death within a few days
300,000	Radiation dermatitis	Immediate blistering of skin

*These are general guidelines – individual patients will vary in their response to acute radiation exposure at various doses

Various medical effects and the required skin dose to produce them

Condition	Skin Dose (see note)
Erythema	600
Dry desquamation	1000
Ulceration	2000
Dermatitis (radiation-induced)	2500
Epilation	300

Note: Patients exposed to large doses of beta radiation can have very high dose to the skin with no corresponding whole-body exposure. Similarly, skin burns may affect only a part of the whole body.

Chronic exposure to low levels of radiation

Everyone is chronically exposed to low levels of background radiation, and this exposure appears to have no adverse effects. However, there are many questions about the effects of exposure to low levels of radiation above background levels, and this is one of the most contentious areas in the radiation safety profession. There are currently two primary models, each of which will be discussed briefly. This section may be of interest to all medical staff because, even in the absence of radiological incidents, most medical personnel are exposed to low levels of radiation from x-rays, fluoroscopy, or CT procedures.

The most serious concern is that long-term exposure to low levels of radiation may lead to cancer later in life. Cancer induction is known as a stochastic effect; an effect that may happen, and for which the probability increases with increasing dose, but that is not necessarily guaranteed. There may (or may not) be a threshold level below which stochastic effects occur; this is the discussed in the following sections. The two competing models describing the risk of cancer resulting from a given dose of radiation are the Linear, No-Threshold (LNT) model and the Threshold model. There are variations on both of these themes that will not be discussed.

As noted above, the primary risk attending chronic exposure to radiation is an increased risk of cancer. As described below, there is some disagreement regarding the exact risk from a given dose of radiation. However, even under the most conservative risk estimates, exposure to 1 rem per year over a 50 year working lifetime will increase the risk of cancer by about 2.5% (assuming a risk of 5×10^{-4} cancer deaths per person-rem of exposure).

The risk of radiogenic cancer comes from the chance that radiation will damage DNA, that the DNA will not be repaired properly, and that the gene(s) damaged can contribute to oncogenesis. For example, damaging the p53 gene, which codes for a DNA damage repair protein, may lead to an accumulation of DNA damage that would have otherwise been repaired. This, with time, can cause a cell to become carcinogenic.

A secondary risk stemming from radiation exposure is cataract formation, a deterministic effect with a threshold of about 200 rads, following an acute exposure, or about 300 rads with chronic radiation exposure.

➢ *Linear, no-threshold model*

The LNT model is the most conservative, meaning that it predicts the highest level of risk for any given radiation exposure. This model says that any exposure to radiation in excess of background levels is potentially harmful, and that the risk of getting cancer is directly proportional to the radiation dose received. LNT is the basis for radiation regulatory policies in the US and, indeed, in virtually every nation on Earth. The LNT model predicts 5 additional cancer deaths for every 10,000 person-rem of exposure. So, under this model, a single person with a lifetime radiation exposure of 10 rem will have 5 chances in 1000 (about 0.5%) of getting cancer from this exposure. Alternately, this model also predicts that exposing 10,000 people to a dose of 1 rem each will result in a total of 5 additional cancer deaths among those exposed.

One problem with the LNT model is that it cannot be confirmed at low levels of exposure because of the statistical "noise" in the epidemiological studies performed. Because of this, the Health Physics Society has specifically advised against calculating risk for any exposures of less than 10 rem to any person. In addition, the International Council on Radiation Protection has advised against the mis-use of what is called collective dose – the second example given above. According to the ICRP, if the most-exposed individual receives an insignificant radiation dose, it is inappropriate to calculate the cancer risk to an entire population receiving that level of exposure or lower exposures. One analogy that comes to mind is with stones. One ton is equal to one million grams. There is no doubt that dropping a one-ton rock on somebody's head will crush them. The ICRP wants to avoid saying that throwing a million one-gram rocks at each of a million people will lead to one person being crushed to death. In reality, we'll have a million irritated people, but nobody will be crushed. Similarly, exposing a million people to low doses of radiation probably won't make anyone sick, even if the collective dose is high.

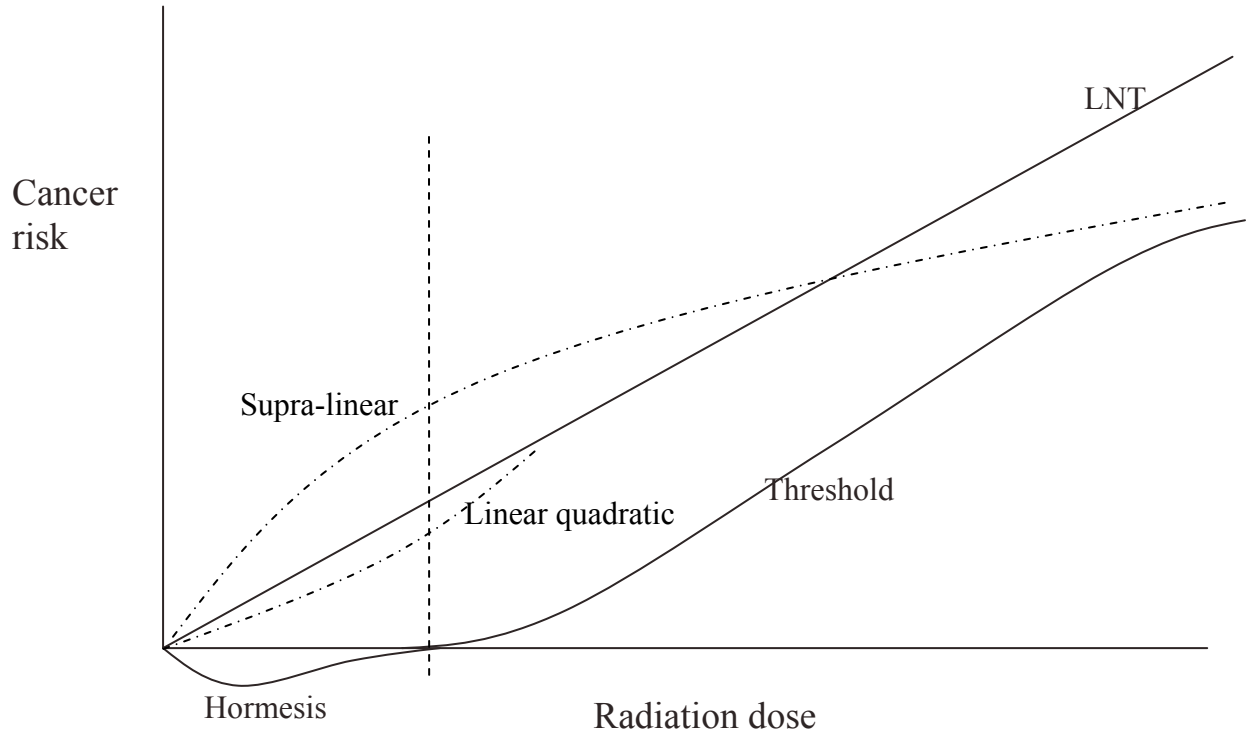
➢ *Threshold models*

Another line of thinking suggests that there may be no adverse effects at all from exposure to low levels of radiation; that there may be a threshold, below which we see no risk. Under threshold models, there is a certain level of exposure that is completely safe and it is only above that threshold that we begin to see an increase in cancer risk. Virtually all known harmful agents exhibit threshold effects.

One variation on the threshold model is the suggestion that exposure to low levels of radiation may produce beneficial effects. This is called hormesis, and it is not as far-fetched as it might seem. We can all name substances that exhibit hormetic effects, including water, vitamin D, selenium, and aspirin. The theory behind hormesis is that, by providing a continuing challenge to our natural DNA damage repair mechanisms, these mechanisms are kept at their peak efficiency and are better able to repair the spontaneous DNA damage that takes place all the time. Some studies of people living in high natural background radiation areas and those who are occupationally exposed to radiation suggest that one of these models may be more accurate than LNT in describing the risks from radiation exposure, but the evidence is not definitive and the debate will likely continue for some time to come.

Under LNT, the risks of developing cancer from occupational radiation exposure are about the same as the risks of any other occupational illness or injury – about one in 10,000. By comparison, the background cancer death rate is about 1600 in 10,000 (16%), and about one

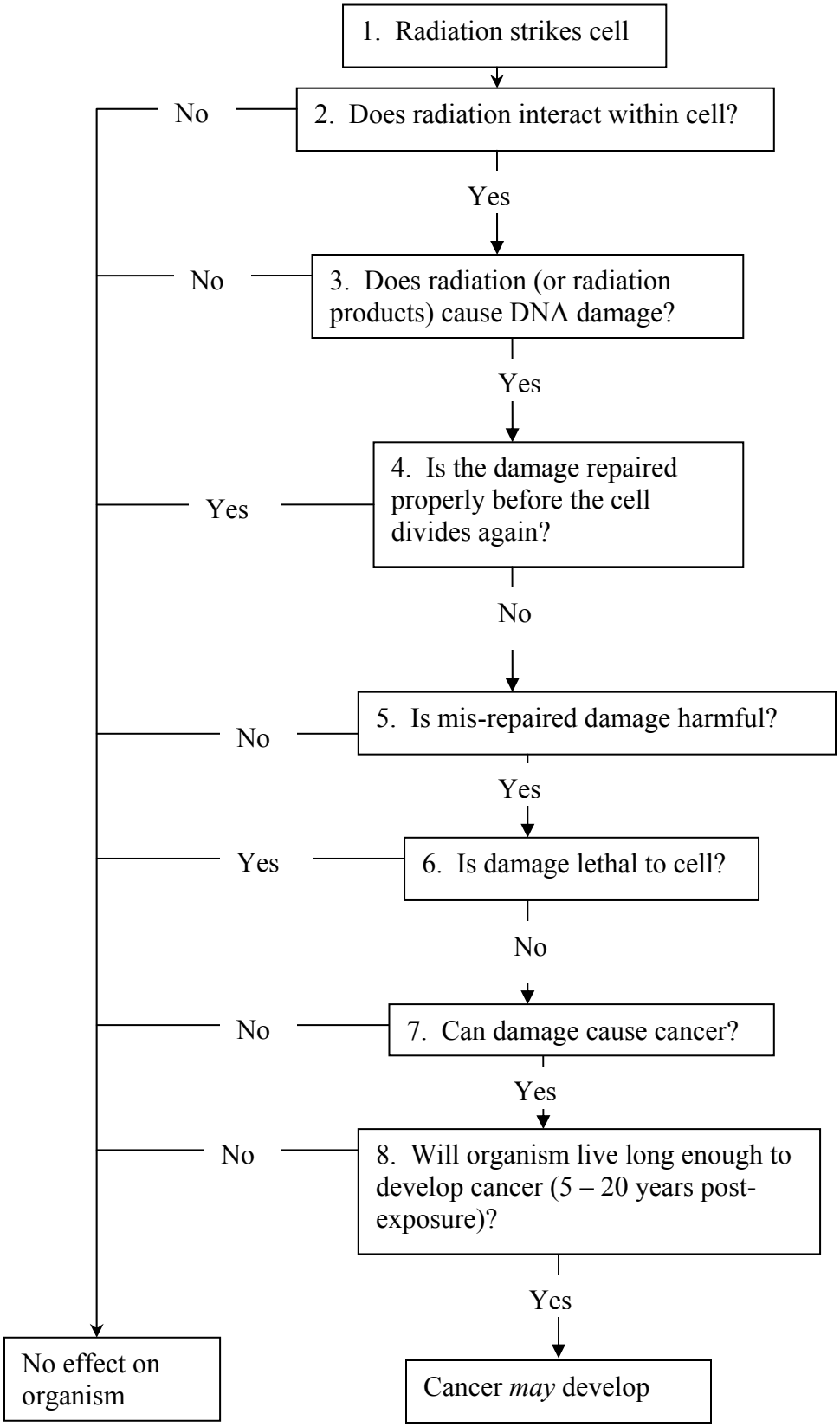
person in 7000 dies each year in traffic accidents (over 40,000 in the year 2000). For the vast majority of radiation workers, the drive to work is far more hazardous than their occupational radiation exposure, even using the LNT model.



Reproductive effects of radiation exposure

Radiation has been used for medical purposes for about a century, and in that time, innumerable men and women have been exposed to radiation. This includes tens or hundreds of thousands of pregnant women, and many pregnant women were also exposed to radiation during the atomic bombings in Japan in 1945. Among all of these women, prenatal radiation exposure of less than five rem to the fetus has never been shown to have resulted in birth defects. Higher levels of fetal radiation exposure have been known to lead to birth defects; primarily mental retardation, low birth weight, and low organ weight. On the next page is a table that shows the medical recommendations (from Lester et al.) for several combinations of fetal radiation exposure and post-conception age.

Males exposed to high levels of radiation may experience temporary reproductive effects. Following a dose of about 15 rads to the testes, there may be minor changes to the sperm cells, and these changes will usually reverse them selves in a period of several weeks to several months. At higher doses (50 rads and higher) males are increasingly likely to experience temporary sterility that may last from a few to several months; the duration depends on the radiation dose received. However, studies of Hiroshima and Nagasaki survivors and those receiving diagnostic and therapeutic medical radiation show evidence that pre-conception radiation exposure to men or women will result in birth defects. Similarly, there is no evidence that radiation exposure leads to heritable mutations in humans, although such effects have been noted in some animal studies.


1. Radiation strikes cell
No
2. Does radiation interact within cell?
Yes
No
3. Does radiation (or radiation products) cause DNA damage?
Yes
Yes
4. Is the damage repaired properly before the cell divides again?
No
No
5. Is mis-repaired damage harmful?
Yes
Yes
6. Is damage lethal to cell?
No
No
7. Can damage cause cancer?
Yes
No
8. Will organism live long enough to develop cancer (5 – 20 years post-exposure)?
Yes
No effect on organism
Cancer *may* develop

Radiation exposure and the pregnant woman

Although every radiographic procedure is different, there are some general statements that can be made. One is that radiographic procedures (x-ray, CT, fluoroscopy), administered above the diaphragm (e.g. head, chest) or below the knees will not give a significant radiation dose to the fetus. It is also safe to say that the fetal radiation dose from a single CT scan or from several x-ray films is not high enough to cause birth defects or to call for a therapeutic abortion. Finally, medically necessary radiation should be administered as necessary if it is not possible to determine a patient's pregnancy status. If delaying a radiographic procedure may result in the patient's death or in serious complications, the procedure must be administered promptly, and the reproductive implications discussed after the patient is stable and awake.

The primary factors influencing fetal radiation dose effects are the fetal radiation dose and the post-conception age. Fewer than two weeks post-conception is sometimes called the "all or nothing" phase, during which either the fetus will spontaneously abort (generally appearing to be a late menstrual period) or will implant and lead to an uneventful pregnancy. Between the second and fifteenth weeks, the fetus is most sensitive to the effects of radiation owing to tissue differentiation, organogenesis, and rapid growth. During this period, it is still not necessary to consider terminating the pregnancy on account of radiation risks for any fetal dose of less than 5 rem if there are other maternal risk factors present, or for a dose of less than 15 rem in the absence of other risks. After the fifteenth week of pregnancy, the fetus is more resistant to the effects of radiation, and it is possible to receive a fetal dose of up to 15 rem before terminating the pregnancy should be considered.

The exact fetal radiation dose must be calculated for every case of exposure, based on information on file at each hospital. As a rule of thumb, until accurate dose calculations can be performed, you may make the following assumptions:

- 1 x-ray that images the uterus will give a fetal dose of about 100 mrem
- 1 CT that images the uterus will give a fetal radiation dose of 2-5 rem
- Fetal dose from fluoroscopy is no more than 1 rem for 1 minute of machine "on" time

These are only approximations, and the actual dose to the fetus must be calculated by a qualified and competent medical physicist or health physicist. However, they are reasonable estimates and, for most equipment, are likely to be high rather than low estimates.

Medical recommendations following fetal radiation exposure (From Wagner et al., 1997)

Fetal age (weeks)	Fetal dose (rem)	Recommendations
0-2	any dose	no action necessary
2-15	<5 rem	no action necessary
	5-15 rem	May consider terminating pregnancy, depending on other risk factors
15 +	<5 rem	no action necessary
	5-15 rem	no action necessary
	>15 rem	may consider terminating pregnancy, depending on other risk factors

Chapter 3: Characteristics of a Radiological Terrorist Attack

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Introduction

Since June, 2002 we have become aware of the arrest of a suspected radiological terrorist (e.g.,, Warrington 2002), al Qaeda plans for constructing radiological weapons (El Baradei 2003), and the availability of large numbers (probably over 100,000) of "orphaned" radioactive sources in the world, thousands of which are sufficiently strong to cause harm (Gonzalez 2004). According to the International Atomic Energy Agency (IAEA), there have been nearly 300 attempted radioactive materials smuggling incidents in the last decade. These recent events have been widely reported (Warrick 2003a,b,c), leading to the perception that the threat of a radiological attack is a new threat, and one that may lie in the near future.

Table 1: Some important RDD-related events

Date	Place	Event*
1997	Russia	Chechen terrorists set, but do not explode, bomb with Cs-137 in a Moscow park
June, 2002	US	Jose Padilla arrested for alleged "dirty bomb" plot
Dec, 2002	Ecuador	Theft and ransom of 5 industrial indium sources, 3 sources returned, 2 unaccounted for
Dec, 2002	Nigeria	Theft of well-logging Cs-137 source, found in Germany in Sept, 2003
May, 2003	Tbilisi, Georgia	Police stop attempt to smuggle radioactive sources into Turkey or Iran
June, 2003	Bangkok, Thailand	Police arrest man attempting to sell Cs-137 for over $200,000

In actuality, the idea of a dirty bomb goes back at least a half-century. During the Korean War, General Douglas MacArthur suggested sowing dangerous levels of radioactivity along the Korean-Chinese border to prevent further Chinese involvement in Korea following the presumed United Nation's victory in Korea (Manchester 1978). Even earlier, in 1941, the National Academy of Sciences explored the idea of radiological warfare in the form of bombs that would distribute radioactivity in enemy territory (Ford 1998). In the 1980s, Saddam Hussein is thought to have experimented with Radiological Dispersal Devices (RDDs), eventually giving up on them for reasons to be outlined below (Muller 2004). And, in fact, the most recent incarnation of RDDs is not even a terrorist innovation; al Qaeda appears to have got this idea from watching US news broadcasts in the late 1990s (Eng 2002). Some have called RDDs a "poor man's nuclear weapon" while others have referred to them as "weapons of mass disruption."

In recent years, the first potential radiological terror event was by suspected Chechen terrorists in Russia (NOVA 2003). It is also possible that al Qaeda produced an RDD (AP 2003). This, and

* Information in table taken from Warrick, 2003a

other events, are summarized in the previous table. However, we have become increasingly aware that radiological materials remain available for misuse. In this paper are discussed the expected effects of a successful RDD attack and suggested strategies for responding to such an attack. Finally, some suggestions are made as to how the risk of an RDD attack may be lessened and, if one is carried out, how the aftermath may be managed. First, however, it is necessary to define some basic terms and concepts.

Radiological versus Nuclear Weapons

There is a tendency to confuse nuclear and radiological weapons when, in fact, the differences, as explained below, are profound.

- ***Nuclear weapons***

In a nuclear weapon, energy is produced via the fission of uranium or plutonium atoms, in particular, atoms of either U-235 or Pu-239. The process is similar to that which takes place in a nuclear reactor, but the characteristics of a nuclear weapon are such that the energy is released in a very brief period of time, causing an explosion rather than the controlled production of energy*. The nuclear explosion itself can be devastating, as was seen in Hiroshima and Nagasaki, but the nuclear (fission) bomb can also be used to initiate a thermonuclear (fusion) explosion, which is even more powerful.

Constructing a nuclear weapon is not an easy matter, but the theoretical details were worked out long ago. We must also remember that the U.S. constructed nuclear weapons with the technology available in the 1940s, and any nation with this level of technology is, in theory, capable of doing so today. Luckily, most nations lack the national desire and the resources necessary to develop nuclear weapons, and international safeguards have limited the abilities of rogue states to do so, although these safeguards have been ineffective in the cases of some nations. From a technical standpoint, the limiting factor in nuclear weapons development is the production of weapons-grade uranium or plutonium; producing these components is extremely difficult, time-consuming, and expensive and is difficult to accomplish undetected. It is also beyond the financial resources of most nations.

Nuclear and thermonuclear explosions are extraordinarily destructive. Consider: the bomb set off in Oklahoma City was equivalent to a few tons of TNT. The bomb detonated over Hiroshima was equivalent to 10,000 Oklahoma City-type bombs. In Oklahoma City, somewhat fewer than 200 people were killed and one building was destroyed, whereas the Hiroshima bomb killed nearly 100,000 people and destroyed virtually an entire city. Nuclear weapons detonation generates shock waves, heat, radiation, and large amounts of radioactive fallout, all of which can be extremely damaging. With nuclear weapons, we see extensive damage to structures, extensive casualties, and the loss of city utilities and services over a large area.

Discussion of nuclear attacks is beyond the scope of this chapter. There are, however, a great many references on this subject. Among the best are works by Glasstone and Dolan (1977) and the North Atlantic Treaty Organization (NATO 2004), both available on-line and in print.

* It bears mention that commercial nuclear reactors cannot explode with a nuclear yield; nuclear weapons contain much higher concentrations of the fissionable isotopes (U-235 or Pu-239) and the low enrichment of commercial reactors makes a nuclear explosion physically impossible.

Radiological weapons

Radiological weapons are in no way similar to nuclear weapons. In a radiological weapon, terrorists would presumably add radioactivity to a "conventional" terrorist bomb so that the bomb would spread radioactivity when it detonated. This means that the physical damage from any such "dirty bomb" is limited to the amount of damage that can be caused by the bomb itself. As we have seen in Oklahoma City, Indonesia, and the Middle East, even this level of explosion can be quite damaging, but nowhere near as catastrophic as a nuclear explosion. An RDD is simply a "normal" bomb that has been "dirtied up" with radioactive materials in order to spread panic and cause civic and financial disruption.

The health effects of an RDD, then, are similar to those of any terrorist bomb, plus the health effects of radioactive materials, and the radiological health effects depend strongly on the weapon's radiological characteristics. The factors controlling these radiological health effects include the radioisotope used, the type of radiation emitted, the amount of radioactivity used in the weapon, and the route of exposure (e.g., inhalation, ingestion, external radiation). Under most circumstances it is likely that a radiological attack, while disruptive, will probably not lead to widespread radiation sickness at the time of the attack or to cancer epidemics in later years. Accordingly, a city subjected to a radiological attack must be prepared to deal with a large number of "worried well", many contaminated or potentially contaminated people, and large cleanup costs; but the physical damage will likely be limited to the area near the explosion itself. A "stealth" radiological attack* would be less physically damaging, but potentially more disruptive because of the potential for contamination to spread beyond the original attack site before detection.

Making a Radiological Dispersal Device (RDD)

To successfully launch a radiological attack, a terrorist organization must be able to find a way to obtain and disseminate radioactive materials. These issues are discussed in the following sections, and the problems they pose may give some insights into methods by which the risk of radiological attack may be mitigated. Various methods of obtaining radioactive materials and assembling them into an RDD have been the subject of much recent work (Barnaby 2004; Allison 2004; Ferguson and Potter 2004).

The effects of acute radiation exposures

Radiation dose (rem)	**Effect**
0.3	Natural background radiation exposure (average) – no expected effect
10	0.5% risk of radiation-induced cancer
100	Mild radiation sickness in about 10% of the population
350	LD50 dose with no medical treatment
750	LD50 dose with adequate medical care (including immune system support)
1000	LD100 with current standards of medical treatment

* It is possible that a terrorist organization may work to contaminate a city surreptitiously by spreading radioactivity in the airport, the subway, on city streets, and so forth. Such an attack would trade immediate panic for longer-term uncertainty and greater levels of civic disruption.

What Makes a "Good" RDD Isotope?

A great deal of attention has been given to the question of what sort of radioactive materials are at the highest risk of being used in an RDD attack. To some extent, the selection of materials will reflect the terrorists' aims (e.g., widespread contamination versus radiation injury), but a more important consideration may be simply which radioactive materials are available in large quantities. In general, it is thought that the selection of radioactive materials will depend on a combination of factors:

- *Availability* of a particular isotope. One must be able to obtain an isotope in order to use it. Even an "ideal" isotope, if unavailable, cannot be made into an RDD.
- Availability of an isotope in *large quantities*. Unless an isotope can be found in large quantities, an RDD attack will be forced to take place on a small scale.
- *Ease of use*. An organization must be able to work with an isotope to put it into a form that can be used for the intended purpose. Soluble cesium chloride powder, e.g., is easier to fashion into a dispersal device than is insoluble cobalt alloy.
- *Ability to shield*. An isotope with very penetrating radiation is more difficult to shield and, hence, more difficult to work with safely and to hide, although such isotopes yield a higher radiation dose for the same amount of material.
- *High activity level*. More highly radioactive materials (those with a shorter half-life) produce more radiation for a given mass and volume of isotope.
- *Sufficiently long half-life*. A very short-lived isotope (e.g., Tc-99m with a half-life of 6 hours) can be intensely radioactive, but decays to stability in the space of only a few days, making for only a short-lived contamination problem. However, even some short-lived isotopes can cause problems; I-131 has a half-life of only 8 days, but is still capable of causing contamination problems for a few months after an incident. Some of these properties are provided in Tables 3, 4, and 5 for some of the most commonly used medical, research, and industrial isotopes.

The availability of a particular radioactive isotope depends on many factors also, including the prevalence of the isotope in the quantity desired, the security surrounding sources of the activity desired, the safety, and so forth.

Obtaining Radioactive Materials

In recent years the attention of those involved in RDD prevention has focused on two major possibilities: the risk that terrorists will steal radioactive sources from a domestic licensee and the risk that the radioactive materials will be brought in from overseas (and sources from overseas may be either or stolen or purchased – legally or on the black market). Accordingly, prevention efforts have largely focused on securing radioactive sources against theft and securing borders against the illicit importation of large amounts of radioactivity.

Perhaps the best single summary of the availability of commercial radioactive materials for illicit use is the one authored by Charles Ferguson of the Monterey Institute of International Studies (Ferguson et al. 2003). This report discusses in detail the manufacture and distribution of commercial radioactive sources and their properties.

Properties of various medical therapy sources

Isotope	*Half-life*	*Photon Energy (MeV)*	*Specific activity (Bq gm-1)*	*Γ (mSv hr^{-1} MBq^{-1} at 1 m)*	*Source activity (MBq-typical)*	*Source size (mm)*
^{60}Co [1, 2]	5.27 yrs	1.17 1.33	4.18x10^{13}	3.703x10^{-4}	A few tens to several thousand MBq	A few mm to a few cm in length
^{103}Pd	17 days	0.0202	2.75x10^{15}	6.219x10-5	55.5 - 74	0.5 x 5
^{125}I	60 days	0.027	6.42x10^{14}	7.432x10-5	18.5	0.5 x 5
^{137}Cs	30.2 yrs	0.662	3.22x10^{12}	1.032x10^{-4}	185 - 740	A few mm to a few cm in length
^{192}Ir	74 days	0.317	3.39x10^{14}	1.599x10^{-4}	18.5 (LDR seeds) 37,000 (HDR src)	Seeds about 0.5 x 3
^{198}Au[1]	2.7 days	0.412	9.04x10^{15}	7.882x10^{-5}	18.5 - 74	0.8 x 2.5
^{226}Ra[1]	1600 yrs	0.186	6.35x10^{10}	3.274x10^{-6}	185 - 925	1 x 10

1 No longer used extensively in many nations

2 A gamma knife may contain about 200 sources of 30 Ci (1.1 TBq) each

Properties of various nuclear medicine isotopes

Isotope	*Half-life*	*Primary Emission*	*Energy (MeV)*	*Specific Activity (Bq gm-1)*	*FGR 11 ALI Ingestion/Inhalation (MBq)**	*Typical administered dose (MBq)*
^{18}F	1.8 hrs	Positron Photon	0.634 max 0.511 (x2)	3.5272x10^{18}	2000 / 3000	555
^{67}Ga	3.3 days	Photon	0.093	2.2217x10^{16}	300 / 500	370
^{89}Sr	50.6 days	Beta	1.49 max	5.6303x10^{12}	20 / 30	148
^{90}Y	64 hrs	Beta	2.28 max	2.0137x10^{16}	20 / 30	1480
^{99}Mo	66 hrs	Beta	1.2 max	1.7561x10^{16}	40 / 50	18.5-111 GBq in new generator
^{99m} Tc	6.01 hrs	Photon	0.141	1.9444x10^{17}	3000 / 6000	74-1480
^{123}I	13.1 hrs	Photon	0.159	7.0905x10^{15}	100 / 200	3.7-111
^{125}I	60.1 days	Photon	0.027	6.4207x10^{14}	1 / 2	74-1850
^{131}I	8.04 days	Beta Photon	0.606 max 0.364	4.5817x10^{15}	1 / 2	0.37-9250
^{201}Tl	73.1 hrs	Photon	0.071	7.8045x10^{15}	600 / 800	74-185

* EPA, Federal Guidance Report Number 11

Properties of various isotopes used in research

Isotope	*Half-life*	*Emission*	*Energy (MeV)*	*Specific activity (Bq gm-1)*	*FGR 11 ALI Ingestion/Inhalation (MBq)* [1]	*Stock vial or source activity (MBq)*[2]
Research isotopes – usually from stock vials						
^{3}H	12.3 yrs	Beta	0.019 max	$3.5869x10^{14}$	3000 / 3000	10-40
^{14}C	5730 yrs	Beta	0.156 max	$1.6513x10^{11}$	90 / 90	10-40
^{32}P	14.3 day	Beta	1.71 max	$1.0573x10^{16}$	20 / 30	10-1000
^{35}S	87.4 day	Beta	0.167 max	$1.5787x10^{15}$	200 / 80	10-40
^{45}Ca	163 days	Beta	0.257 max	$6.5072x10^{14}$	60 / 30	10-40
^{51}Cr	27.7 day	Photon	0.005	$3.4078x10^{15}$	1000 /700	10-40
		Electron	0.320			
^{125}I	60.1 day	Photon	0.027	$6.4207x10^{14}$	1 / 2	20-400
		Electron				
Isotopes used in neutron sources (e.g. PuBe or AmBe 4 sources)						
^{238}Pu	87.8 yrs	Alpha	5.499	$6.4345x10^{11}$	0.03 / 0.0003	4000-40,000 [3]
^{241}Am	432 yrs	Alpha	5.486	$1.2769x10^{11}$	0.03 / 0.0002	4000-40,000 [3]
		Photon	0.060			
^{252}Cf	2.64 yrs	Alpha	6.118	$1.9848x10^{13}$	0.09 / 0.0007	4000-40,000 [3]

1 The ALI (Allowable Limit for Intake) is the amount of an isotope that, when taken up, will give a whole-body radiation dose of 5 rem or a specific organ dose of 50 rem. The ALI will vary according to the route of uptake (inhalation or ingestion) and the chemical form of the isotope. In some cases there are multiple ALIs depending on the chemical form of the isotope; values presented here are the lowest ALIs noted for each isotope

2 Stock vial and source activity vary widely – the ranges given are approximations only

3 Source activity depends on desired neutron flux and can vary widely depending on actual use

4 PuBe and AmBe sources consist of mixture of plutonium (Pu) or americium (Am) with beryllium (Be). These sources are used to produce neutrons.

➢ *Obtaining radioactive materials domestically*

The U.S. government has been stating for over a year that universities and hospitals are considered "soft targets" due to their lack of security and, because of this, they are considered prime candidates for theft. Many hospitals maintain high-activity radioactive sources for therapy and sterilization purposes, and many research institutions maintain high-activity sources for purposes of research. One radiological terrorism scenario suggests that terrorists or professional thieves may attempt to steal radioactive sources from research or medical institutions. Theft of such sources from industrial facilities is considered a somewhat lesser risk because such facilities often contain lesser amounts of radioactivity and because their security is often more stringent. Other possibilities have received lesser levels of attention, although they may be more likely. Some of these are discussed in greater detail in the following section.

It is also possible that terrorists may choose to attack a vehicle making deliveries of radioactive materials or that they would attack radiological facilities (e.g., a hospital's nuclear pharmacy) with vehicle bombs to release the radioactive materials stored on-site. Yet another possibility is that a domestic or foreign terrorist organization could purchase a used irradiator (which are sometimes advertised for sale) from an existing licensee using falsified documents.
Finally, it is also possible, indeed likely, that terrorists may attempt to obtain radioactive materials overseas and import them into the US in a cargo container. In fact, it seems likely that

multiple attempts to do this have already occurred (Warrick 2003a, b, c, d) and the reported instances are doubtless only a fraction of total attempts. Some recent (since January 1, 2002) incidents involving the possible loss or illicit transportation of radioactive materials are summarized in Table 1. Sources of radioactive materials could include radio-isotopic thermal generators, such as those found in the nation of Georgia in early 2002, abandoned medical therapy sources such as those that caused the contamination incident in Goiania, Brazil (mentioned in more detail in the following sections), or theft of a large radioactive source as happened in Nigeria in 2002.

In summary, there are a number of ways a terrorist group can either "legally" or illegally obtain radioactive materials for use in a radiological weapon. Once obtained, however, the group will still need to fabricate a radiological weapon, move it into position undetected, and use it.

Constructing an RDD

At its most basic, assembling an RDD consists of constructing an explosive device and adding radioactive materials to it. Complications arise from the fact that radioactive materials are not necessarily easily dispersible, and a large radioactive source can emit life-endangering levels of radiation. Obviously, many terrorists are not deterred by sacrificing their lives, but a terrorist will need sufficient working time to accomplish something – it is hard to construct a device if workers receive an incapacitating radiation dose in only 15 minutes. In addition, large quantities of unshielded radioactive materials produce high levels of radiation, making an RDD "factory" easier to detect by law enforcement officials. Accordingly, working with a very high level of radioactivity will necessitate using lead shielding and/or remote manipulators, which are not necessarily easy to obtain.

Dispensability is another attribute of "good" RDD materials, and some sources are more easily dispersed than others. In the recent television show on RDDs (NOVA 2003) it was mentioned that Cs-137 is often found as an easily dispersed powder. Cobalt, on the other hand, is usually used as a metal alloy and Sr-90 is often found in ceramic form. These latter forms must be processed somewhat in order to be made into an RDD; failure to process them would lead to a relatively short-range dispersal of radioactive materials and would blunt the potential impact of the attack. Although radioactive materials come in many physical and chemical forms, large sources are more likely to be restricted to a few well-tested physical forms, primarily for manufacturing considerations, and these most likely physical forms will help to dictate the steps necessary to construct an RDD (Levi and Kelly 2002).

Preventing an RDD Attack

To construct an RDD, a terrorist group must obtain radioactive materials, use those materials to fabricate a weapon, deliver the weapon to the attack site, and detonate the device. Each of these steps suggests intercessionary measures that can be used to help prevent an attack.

Obtaining radioactive materials requires access to the materials; radioactive sources must be either purchased or stolen. Legal purchase in the U.S. requires possession of a radioactive materials license, and vendors are not allowed to sell radioactive materials except to properly licensed customers. Terrorist groups could accomplish this via subterfuge (e.g., copying or

altering a legitimate radioactive materials license or applying for a license under false pretenses). A terrorist group can also take advantage of existing bulletin boards on which radioactive sources are advertised, often "free to a good home" by organizations that no longer use them. To transfer a radioactive source legally, it is sufficient to have on-hand a copy of the radioactive materials license of the recipient, which can be supplied by the receiving organization. This leaves open the possibility that a terrorist group could falsify these records to obtain an unwanted radioactive source. To preclude this possibility, regulatory bodies should consider requiring licensing documents be obtained only from a regulatory authority with licensing jurisdiction over the source recipient rather than counting on the integrity of the source recipient.

The most straight forward deterrent to stealing radioactive sources is to increase security via better locking systems, the presence of security guards, alarm systems to indicate a sources theft, and so forth. It is also important to note that radioactive materials licenses are considered public documents and are available for scrutiny by the public. This means that a terrorist organization may be able to obtain copies of licensing documents and use these to identify likely targets for theft. Accordingly, we may wish to remove these documents from public scrutiny.

Radioactive materials obtained overseas must be moved into the US in order to be used against us. This means that containers with large radioactive sources must either emit high levels of radiation or they must contain large amounts of lead. Developing suitable detection instruments may help address this problem. That being said, current radiation detectors are difficult for untrained personnel to use; it may be necessary to develop a new family of radiation detectors that will help avoid some of the errors that have occurred in the recent past*.

Finally, radioactive materials must be transported from the point of entry to the location of fabrication or use. Establishing a network of sensitive radiation sensors around likely target cities can help to detect any but the best-shielded radioactive sources, possibly permitting interdiction prior to use. Aerial surveys may help in this matter, too, depending on the number of available aircraft, detector sensitivity, and the size of the city.

Fabricating an RDD, as noted above, can lead to exposure to dangerously high levels of radiation. This, plus the need to avoid detection may necessitate the use of remote manipulators and/or large amounts of lead shielding. Accordingly, it may be desirable to require lead vendors to report sales of large amounts of lead, remote manipulators, and other such paraphernalia. Although this will not prevent RDD construction, it may at least make it more difficult, more dangerous, or more amenable to detection†.

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* A Customs officer's radiation "pager" alarm led to a ship's being ordered into international waters until subsequent inspection indicated the presence of natural radionuclides in a container of ceramic tiles. In other instances, police have stopped and questioned or searched nuclear medicine patients because of similar radiation pager alarms. These could have been avoided with proper instrumentation.

† Similarly, training physicians to recognize radiation illness or injury may help identify potential RDD plots by noting unusual patterns in radiation-related injury.

Human effects of an RDD Attack

In spite of our best preventative efforts, it is entirely likely that an RDD may still be successfully detonated. If this comes to pass, we must be prepared to work to address and, if possible, minimize the effects of any such attack. To do this we must first understand what some of these effects may be so that actions can be prioritized. In general, we are concerned about the physical effects of the explosion itself and the radiation levels at the site of the attack, the health effects of this radiation exposure on victims and emergency response personnel, and later effects on the city and on our society. Please note, however, that radioactive materials do not need to be spread by an explosive device – radioactive powders can be blown from the top of a tall building with a fan (or a good wind), for example.

➢ *Effects of the Explosion*

There is ample evidence that explosions are deadly, even in the absence of radioactive materials. Oklahoma City, Beirut, Baghdad, and too many other sites have shown us the destructive power of a vehicle full of explosives. In the aftermath of any such attack, we may expect to see fires, damaged or collapsing structures, and victims of the blast. Even without the presence of radioactive materials, we can expect to see these effects plus accompanying injuries.

➢ *Radiological Health Effects*

Radiological health effects are more difficult to describe because of the potentially great variability in exposure due to actual exposure pathway (e.g., inhalation or ingestion) and the dose to which people are exposed. External exposure to minor amounts of Sr-90 contamination, e.g., may lead to no noticeable health effects while inhalation of large amounts of Am-241 may prove fatal. Some of these scenarios will be explored and summarized in the following section and its accompanying tables. Table 6 summarizes some of the factors that affect the biological severity of a radiological attack.

In the event of an RDD explosion, it is reasonable to expect that those persons closest to the explosion will be both most badly injured and most heavily contaminated with radioactivity. This poses an obvious dilemma to emergency and medical responders, who will be concerned about their own exposure to radioactivity. Although the general consensus is that radioactively contaminated victims and patients pose little or no risk to those caring for them (NATO 2004), this is not common knowledge, and unwarranted fears of radiation and radioactivity have caused caregivers to delay or deny needed care in the past*.

* Although this has not been widely documented in the literature, the author has spoken with emergency responders and medical caregivers from New York City, Orlando, Cleveland, Rochester NY, Los Angeles, and other cities who have stated their reluctance to provide medical care to radiological patients for the reasons stated.

Factors influencing the biological impact of a radiological attack

Factor	Influence
The kind of radiation emitted by the isotope	Alpha and beta radiation are not external radiation hazards, but alpha radiation gives a very high internal dose
The energy of emitted radiation	High-energy radiation causes more harm than low-energy radiation because it's more penetrating. High-energy gamma radiation penetrates more deeply into tissues and travels further through air than low-energy radiation
Chemical form of ingested or inhaled isotopes	Soluble radioactive materials are more easily absorbed by the intestines and lungs.
Biokinetics of a particular element	Some elements (e.g. carbon and hydrogen) are distributed evenly through the body while others (e.g. plutonium) concentrate in particular organs. Some elements are rapidly cleared from the body (e.g. I) while others remain for years or decades (e.g. U).

- ***Inhalation pathway***

In general, inhalation is the most damaging exposure pathway, and inhalation of alpha radiation is the most dangerous because alpha radiation deposits a large amount of energy in a relatively short ionization path. One study has suggested that a single alpha particle can cause oncogenic transformations in cells (Wu et al. 1999; Grosovsky 1999) while others have shown that inhalation exposure to large levels of alpha-emitting isotopes can cause significant other health problems, including death (NAS 1988; NAS 1998; Alvarez 2003).

Inhaled alpha-emitting radioactivity can be a significant health hazard under certain circumstances (Zimmerman and Loeb 2004). If evenly distributed in air and inhaled, one gram of Am-241 (which contains nearly 3.5 Ci) can produce over one million doses of 500 rem or more to the whole body over the course of a year. Although this dose, if accumulated in a very short period of time, would be lethal to 50% of those receiving it, when protracted over the course of a year, it is not as damaging. Nevertheless, it is reasonable to assume that many of those exposed will develop fibrosis of the lungs, radiation pneumonitis, or other pulmonary diseases in the short term, some fatally so; others may die of radiation-induced cancers over the longer term.

Although this may not lead to an immediate influx of patients, over the course of a year and longer, we can expect to see a large number of patients with these pulmonary diseases in the first year post-exposure and many added cases of lung cancer in the years or even decades following the attack. Luckily, it may not be plausible to assume that one million people can be exposed in this manner because of the difficulty of producing such an even distribution of Pu*, but it may be possible to introduce radioactivity into the ventilation system of a large building, theater, sports arena, or other enclosed space.

Radiation dose via the inhalation pathway is determined by the radioactivity concentration in air, particle size, the isotope present, and the type of radiation emitted. Lung (and whole-body)

* Although it is easy to imagine scenarios such as crop-dusting, aerosol sprays, dissemination into ventilation ducts, *etc*. that can produce relatively uniform, large-scale distribution of radioactive powders.

radiation dose increases as airborne radioactivity concentrations increase as particle size decreases until the particles are so small that they behave like a gas. A dense spray of any isotope is more dangerous than a light spray, an isotope with a high dose conversion factor per unit activity inhaled is more dangerous than one with a low dose conversion factor, and alpha emitting isotopes are more dangerous than others. This is demonstrated in the following table, which shows the amount of inhaled radioactivity needed to produce a radiation dose of 5 rem to the whole body (the Allowable Limit for Intake, or ALI). This clearly shows that inhaling alpha-emitting radioactive materials if far more dangerous than inhaling an equivalent amount of gamma-emitting radioactivity.

The Allowable Limit for Intake (ALI), specific activity (Curies per gram of isotope), and the mass of 1 Ci of activity for some likely RDD isotopes

Isotope	*half-life (yrs)*	*atomic mass (amu)*	*ALI* (μCi)*	*specific activity (Ci/gm)*	*grams per Curie*
Cs-137	30.17	137	200	86.91	0.01151
Co-60	5.27	60	30	1136.01	0.00088
Am-241	432.7	241.06	0.0008	3.44	0.29038
Pu-238	87.7	238.05	0.0007	17.21	0.05812

It is likely that a "dirty bomb" attack will produce large quantities of relatively large particles that will settle out near the site of the explosion (Alvarez 2003). This could lead to relatively high exposure levels to persons near the attack site and lesser exposure to others. Persons upwind of the attack will, of course, receive little or no inhalation dose. It is also possible, however, to disperse radioactive materials by blowing powder from a tall building, from an aircraft, or from a vehicle. In this case, particle size is likely to be more uniform and, indeed, the material may be processed to achieve a predetermined optimal particle size†. In such cases, it is entirely possible that a large number of persons may receive enough radioactivity to produce a high radiation dose. For example, inhaling 1 μg (1.13 mCi) of Co-60 powder in soluble form will produce a whole-body dose of about 170 rem. This radiation dose can cause radiation sickness, although it is not likely to be fatal to the exposed individual.

Respiratory protection can be effective in reducing the risk of inhaled radioactive particles provided the protection can effectively filter the particle sizes represented in the event. In the case of a "dirty bomb", most particles will likely be relatively large, but micron- and submicron-sized particles may be generated by burning radioactive materials or by blowing fine radioactive dusts and powders into the air.

* ALI is the Allowable Limit for Intake. Ingesting or inhaling 1 ALI will give a person a radiation dose of 5 rem in a year to the whole body, or 50 rem in one year to the most-exposed organ

† Large particles will not penetrate far into the lungs and are relatively easily cleared from the body. Particles that are very small tend to be entrained in the air and may not be deposited in the lungs but, rather, are simply exhaled. "Ideal" particles are those that are sufficiently small to be drawn deeply into the lungs, but large enough to remain during an exhalation – these particles are typically around one micron in size.

➢ *Ingestion pathway*

A large cloud of radioactive particles may be ingested as well as inhaled. People breathing through their mouths because of hard work or excitement can have particles settle in their mouths that are subsequently swallowed. Larger particles settling in the lungs or respiratory passages may be entrained in mucus, swept into the throat, and swallowed. Nervous individuals who bite their fingernails may swallow particles beneath (or on) the nails. Finally, radioactive particles may settle onto gardens or prepared foods.

For insoluble radioactive materials (e.g., cobalt oxide), the ingestion pathway is considered less harmful than inhalation because the ingested materials pass through the digestive system relatively rapidly and are excreted. Soluble radioactive materials may be absorbed by the body and retained with whatever biological half-life is typical for that element; these can range from days to decades, depending on the biokinetics of the particular element. For example, insoluble uranium has an uptake factor of about 0.002 (i.e., 0.2% of ingested insoluble uranium is absorbed into the body) and soluble uranium has an uptake factor of 0.05. Of the uranium that enters the body, 20% enters the mineral bone and is retained with a biological half-life of 20 days, 2.3% enters the mineral bone and is retained with a biological half-life of 5000 days, and the remainder is distributed to other tissues (primarily the kidneys) and is retained with biological half-lives ranging from 6 to 1500 days (Hodge, Stannard, and Hursh 1973).

In general, the ingestion pathway is not considered as serious as the inhalation pathway because of the relatively short biological half-life for materials that are not absorbed into the body. However, both pathways are important for radioactive materials in soluble form, such as CsCl, that can easily enter the body.

➢ *External exposure pathway*

Finally, it is necessary to consider the external exposure pathway, which will be a concern under most circumstances involving gamma-emitting radionuclides. Alpha- and beta-emitting nuclides are not an external radiation concern because of the short range of alpha and beta particles in tissue (about 5 microns and 1 cm maximum range, respectively). The extremes for gamma radiation exposure would occur from the widespread distribution of radioactive contamination (lowest dose) and the placement of an intact irradiator source in a public area (highest dose). This section will also consider an intermediate case in which large amounts of radioactive materials are spread over a relatively small area of one acre.

Radioactive materials regulations restrict access to any areas in which loose surface contamination is present at levels higher than 1000 dpm/100 cm^2 (or about 0.16 Bq/cm^2). Contaminating a large area to these levels can result in access restrictions and contamination controls. If a terrorist group desires to deny use of the greatest area possible and to cause the highest cleanup costs, they may decide to distribute radioactive materials at this level of contamination.

Consider: a 1 Ci (37 GBq) radioactive source decays at a rate of 37 billion disintegrations per second (dps), which is 2.22 trillion dpm. With a maximum allowable contamination level of 10 dpm/cm^2, this level of activity is sufficient to contaminate about 200 billion cm^2 to levels requiring remediation and entry controls. One square meter contains 10,000 cm^2 and there are

one million m^2 in a km^2, so a single Ci of activity can contaminate 22 km^2 (5485 acres). With the specific activity of Cs-137 (87 Ci/g), such a source would contain only 11.5 mg of Cs (less than 20 mg of CsCl), and the dose conversion factor of Cs-137 would produce a radiation dose of about 1.5 μr/hr to a person living on this surface*. Such a radiation dose rate is trivial in that living continuously in such a radiation field will give occupants an added 13 mr (0.13 mSv) per year, about equal to 2 weeks of exposure to natural background radiation. Obviously, the widespread distribution of radioactivity is a regulatory, financial, and social problem, not a health risk.

On the other extreme, terrorists may want to place an intact radioactive source in a public place, attempting to make people ill from radiation sickness. To again use Cs-137 as an example isotope, an unshielded 1000 Ci (37 TBq) radioactive source produces a radiation dose of about 1.032×10^{-4} mSv/hr for each MBq at a distance of one meter. This source, then, would give a radiation dose of about 3.3 Gy/hr (330 r/hr) at a distance of 1 meter. At this exposure rate, a person standing at arm's length from the source would receive a lethal dose of radiation in 2-3 hours and would receive sufficient radiation to cause radiation sickness in about 15-20 minutes. This may seem an alarmingly short time, but we must also consider that it is unusual for a large number of people to spend even 20 minutes at a distance of 1 meter from anything. For example, perhaps 15 people can fit into an elevator (albeit uncomfortably), but elevator rides are relatively short. A larger number of people can fit into a bus or train car, but the dimensions of the car are such that very few people would be within 1 meter of any given spot.

A source placed in a building lobby or on a street corner would face similar limitations in that few people would spend an appreciable amount of time in close proximity to any given location. Only in specific settings, such as sporting events, concerts, movies, or theatre productions can a relatively large number of people be in close proximity for a sufficiently long period of time to experience ill effects from a radioactive source. However, even in such settings, seats are more than a half meter in width, so only a dozen or so people in these settings could receive a lethal radiation dose and fewer than 100 would fall ill from radiation sickness. While these numbers are not trivial (they are higher than the number of people who became ill or died from the 2001 anthrax attacks), they are far fewer than those who have perished in many other terrorist attacks. In addition, radiation safety professionals have a great deal of experience with locating, isolating, and recovering even high-activity radioactive sources; recovering from such an incident would not be a simple matter, but it would be an exercise for which there is ample precedent and for which there exists much expertise.

An intermediate case would occur if terrorists disperse large amounts of radioactivity in a relatively limited space. For example, spreading 1000 Ci of Cs-137 in a space of only one acre would produce radiation levels of about 8 r/hr (using calculations such as those performed above). At this level of exposure, victims and emergency responders would exceed regulatory dose limits for radiation workers in about 40 minutes, but would require over 12 hours of exposure to begin to develop radiation sickness, and over 50 hours to reach the LD_{50} dose (without medical care) of 400 rem. Clearly, while this exposure level is a concern, it is not a health risk for any reasonable work and exposure times.

* These calculations were performed using the MicroShield program, an industry-standard software package. MicroShield was written by Grove Engineering.

Environmental Effects of Radiological Terrorism

In addition to the effects on humans, it is necessary to consider the environmental effects of a radiological attack. Whether distributed through an RDD explosion, sprayed onto food or introduced into the water supply, sprayed onto a crowd, or disseminated in other modes, it is probable that the radioactive material released will end up in the environment at some point. Even radioactivity surreptitiously introduced into a building is likely to be, at some point, introduced into the sanitary or storm sewer system or to escape the building on the clothes or shoes of unsuspecting workers. In these cases, concerns include soil and surface water contamination and the contamination of food or drinking water.

Soil and Water Contamination

Consider the explosion of an RDD. The explosion scatters radioactive materials into the surrounding area, and some radioactivity is lofted into the air by the force of the explosion or by subsequent fires. As this radioactivity settles to the ground, it will likely (in an urban environment) settle onto streets, sidewalks, buildings, parking lots, and other manmade surfaces. Some contamination may drift into parks. Unless all of the contamination is cleaned up before the first rainfall or snow melt, water will carry contamination into storm sewers and into nearby bodies of water. Contamination that settles onto soil will be transported into the soil, either percolating into the groundwater or attaching to clays in the soil. In each of these cases, the radioactive contamination will enter the environment and will migrate according to its environmental mobility.

In the absence of a concentrating mechanism, radiation dose from these isotopes is not likely to exceed that of the original site; this has already been shown to be fairly low. Accordingly, it is safe to say that radiation dose from environmental contamination may be mildly elevated, but it is not likely to be sufficiently high as to present a risk to plants, animals, or humans.

- ***Soils***

Soil column filtration was used to remove contaminants from water until the 1970s. This utilized the cation exchange capacity of clays in soils to attract dissolved ions, binding them to the surface of the clay minerals. Depending on the chemical properties of the exact isotope(s) used, this same phenomenon will cause much of the contamination from a radiological attack to remain in the soil as contamination. This, in turn, can lead to the need for decontamination via soil removal, soil washing, or other methodologies. The need for such decontamination will depend on the isotope(s) used, the concentration of isotope in soil, and the cleanup limit for the particular isotope(s) in question.

- ***Water***

Solubility depends on the chemical properties of a material. Some isotopes are either inherently soluble or are often found in soluble form (e.g., H-3, C-14, Cs-137 as CsCl); these are more likely to become mobile as they dissolve into water (precipitation or surface water) and are

transported from a contaminated site. Dissolved isotopes will be transported until they are removed from the water by ion exchange with rocks or soils, by precipitation, until the water leaves the region of interest, or until they are diluted beyond detectability. Insoluble isotopes (e.g., Co-60) will be carried in water as particles until they are filtered out by soil or other materials or until they settle out in a low-flow area. Contaminant transport is a well-studied phenomenon (see, e.g., the textbook by Domineco and Schwartz (1997)), and the details are beyond the scope of this paper.

Although there is a possibility that dissolved isotopes may enter the municipal water supply, water treatment will remove most of the activity, along with other contaminants to meet drinking water standards (USEPA 2003). The most likely areas to be attacked are urban, which have municipal water treatment, reducing the potential for radionuclide ingestion. Similarly, urban residents are not likely to obtain a large fraction of their food from home-grown vegetables or fruits, reducing radiation dose from this exposure pathway. In short, although there are exposure pathways that can lead to high levels of human radiation exposure, they are unlikely to be seen in the urbanized areas most likely to be attacked. Regarding radiation dose to organisms, it is similarly unlikely that any organisms will receive a high radiation dose with the exceptions noted below.

Some areas may tend to concentrate radionuclides. Low-flow regions of rivers or streams will let particles settle to the bottom, e.g., cesium, which can bind to clays, may concentrate in the top-most soil layers, and iodine that is distributed widely across a pasture can concentrate in cow's milk (Eisenbud and Gesell 1997). Other areas in which chemical or mechanical processes may lead to radionuclide reconcentration are:

1. Sediments at the point a stream or storm sewer enters a river or lake
2. Oxidation-reduction fronts where ground or surface water becomes anoxic
3. Sediments or rough concrete at the bottom of storm sewer pipes
4. Gutters, particularly in cracks and expansion joints
5. Potholes and other depressions paved and natural surfaces
6. Soil horizons which mark changes in soil mineralogy or soil chemistry.

These concentrating mechanisms can lead to elevated radiation dose in limited areas or to small numbers of organisms that, in extreme cases can be unhealthy. In such circumstances, it may be prudent to consider remediating these areas in which reconcentration occurs, even if it is prohibitively expensive to remediate the entire affected area.

Summary

Some terrorists have made no secret of their desire to attack our allies or us with radiological weapons. In the event of a successful radiological attack, we will be faced with a bevy of problems. These include the "normal" disruption associated with any terrorist attack plus the added complications associated with radiological patients and "hot" work. In spite of the fact that any radiological attack is unlikely to lead to mass radiological casualties (indeed, there may be no radiological casualties at all), radiation safety measures and radiological regulations are likely to complicate our efforts.

If we are faced with tens or hundreds of thousands of contaminated (or potentially contaminated) persons, we will need to develop rapid and reasonably accurate field screening techniques to help us concentrate attention on only those persons who require this attention. We may wish to revisit regulatory guidance so that our regulations are based on risk rather than on our ability to detect ever-lower levels of contamination, and it may be necessary to change our medical treatment paradigm from patient-centered to community-centered for the duration of the emergency. In all of this, it will be important to remind emergency response and medical personnel that contaminated patients do not pose a risk to those caring for them (and that universal precautions are usually sufficiently protective), and that it is essential to care for life-threatening injuries first, regardless of a patient's contamination status.

Having said all this, it is safe to assume that no actual incident will meet our expectations and any plans we develop will have to be altered to address the reality with which we will be faced. However, by developing a good set of plans, training to these plans and reasonable variations on them, and by setting in place actions and precautions based on risk instead of technology, we should be able to successfully manage the scene in the aftermath of a radiological attack, manage the city so that essential services are retained, and manage the longer-term consequences so that the city and our society recover as rapidly as possible.

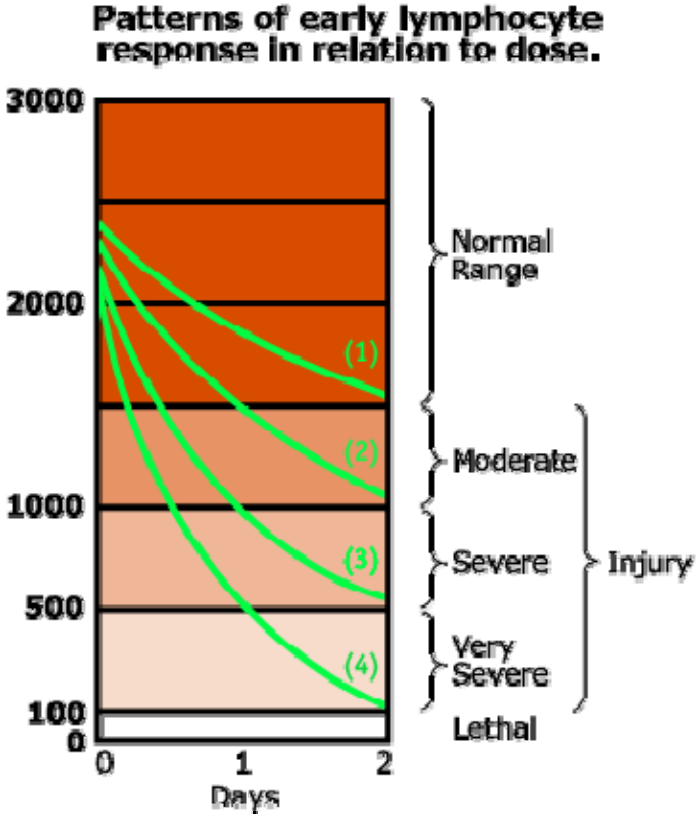
Chapter 4: Hospital Management of Victims/Patients after a Radiological Attack

Determining radiation dose

Radiation dose calculations or estimates are crucial in triage and developing a treatment plan. Patients with less than 100 rem of exposure are unlikely to require any medical attention at all for their radiation exposure while patients who have received in excess of 1000 rem are most likely beyond hope. Between these extremes, the dose a patient receives will help to determine the need for antibiotic support, isolation in a sterile environment, or the need for other actions. Accordingly, it is essential that medical personnel make every effort to determine the likely patient radiation dose as soon as other pressing medical needs are resolved. Several methods for estimating or calculating radiation dose are presented in this section.

- ***Estimating radiation dose based on patient symptoms or biological response***

Exposure to high levels of radiation can cause nausea and vomiting, and the onset to vomiting is related to the radiation dose received. This means that a rough estimate of radiation dose can be made if the time between radiation exposure and vomiting is known. In addition, the blood forming organs are among the most sensitive to the effects of radiation, so tracking blood cell counts over time can also be used to estimate radiation exposure. The following provide some information to help with these estimates.



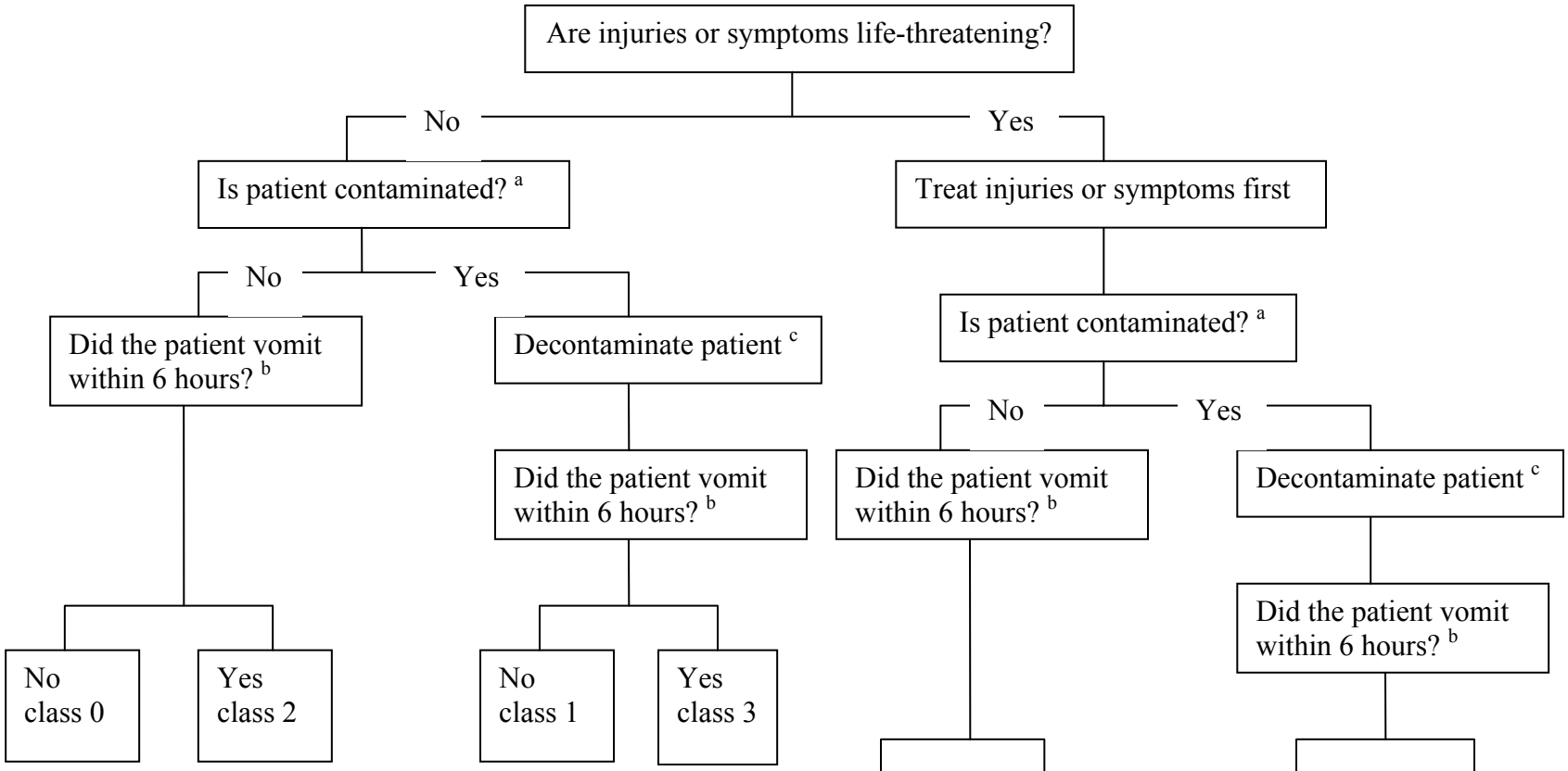
Classical Andrews lymphocyte depletion curves and accompanying clinical severity ranges. According to the data presented in this paper, curse 1-4 correspond roughly to the following whole-body doses: curve 1 - 3.1 Gy; curve 2 - 4.4 Gy; curve 3 - 5.6 Gy; curve 4 - 7.1 Gy.

From Goans, Ronald E., Holloway, Elizabeth C., Berger, Mary Ellen, and Ricks, Robert C. "Early Dose Assessment Following Severe Radiation Accidents," Health Physics 72(4): 1997.

Syndrome phase	Feature	Effects of acute whole-body irradiation or internal exposure in the range of 0-3000 rads					
		0-100	**100-200**	**200-600**	**600-800**	**800-3000**	**>3000**
Prodromal	Nausea, vomiting	None	5-50%	50-100%	75-100%	90-100%	100%
	Time of onset		3-6 hrs	2-4 hrs	1-2 hrs	< 1 hr	Minutes
	Duration		< 24 hrs	< 24 hrs	< 48 hrs	< 48 hrs	N/A
	Lymphocyte count	Unaffected	Minimally decreased	< 1000 at 24 hrs	< 500 at 24 hrs	Drops within hours	
	CNS function	No impairment	No impairment	Routine task performance, cognitive impairment for 6-20 hrs	Simple, routine task performance Cognitive impairment for > 24 hrs	Rapid incapacitation, may have lucid intervals of several hours	
Latent	No symptoms	> 2 wks	7-15 days	0-7 days	0-2 days	None	
Manifest illness	Signs, symptoms	None	Moderate Leukopenia	Severe leucopenia, purpura, hemorrhage, pneumonia, hair loss after 300 rad		Diarrhea, fever, electrolyte disturbance	Convulsions, ataxia, tremor, lethargy
	Time of onset		> 2 wks	2 days – 2 weeks		1-3 days	
	Critical period		None	4-6 weeks, greatest potential for effective medical intervention		2-14 days	1-48 hrs
	Organ system	None		Hematopoietic, respiratory (mucosal) systems		GI tract, mucosal systems	CNS
	Hospitalization	0%	< 5%	90%	100%	100%	100%
	Duration		45-60 days	60-90 days	90+ days	Weeks to months	Days to weeks
	Mortality	None	Minimal	Low with aggressive therapy	High	Very high, significant neurological symptoms indicate lethal dose	

Symptom clusters as delayed effects after radiation exposure				
	Headache Fatigue Weakness	Anorexia Nausea Vomiting Diarrhea	Partial, full thickness skin damage Epilation (hair loss) Ulceration	Lymphopenia Neutropenia Thrombocytopenia Purpura Opportunistic infection

➢ ***How to classify victims of radiological emergencies during first 12 hours following the event***



Class 0 – No contamination, no significant injury, no significant radiation exposure
Class 1 – External contamination, no significant injury, no significant radiation exposure
Class 2 – No contamination, no significant injury, possible high radiation exposure (e.g. irradiator or nuclear attack)
Class 3 – External contamination, no significant injury, possible high radiation exposure
Class 4 – No contamination, significant injury, possible high radiation exposure
Class 5 – External contamination, significant injury, possible high radiation exposure
Class 6 – No contamination, significant injury, possible high radiation exposure
Class 7 – External contamination, significant injury, possible high radiation exposure

[a] See Chapter 12 for radiological survey procedures
[b] See Section 7.2 for more information on dose assessment
[c] See Chapter 9.1.2 for guidance on treating contaminated patients

Class 0: No contamination, no significant injury, no significant radiation exposure

1 Treat minor injuries if present
2 Consider psychological and social needs of victim, family, and friends

Class 1: External contamination present, no significant injury, no significant radiation dose

1 Decontaminate if possible, starting with most-contaminated areas
2 Treat minor injuries that are present
3 Consider psychological and social needs of victim, family, and friends. Assure patients that contamination is not a significant health problem
4 If contamination is found around nose, mouth, or open wounds, consider potential for internal contamination and sample if possible using
5 Bilateral nasal swabs
6 Bioassay (urine, fecal, blood)
7 Consult with radiation medical expert, health physicist, DOHMH, etc. regarding need for bioassay and appropriate collection protocol

Class 2: No contamination, no significant injury, possible significant radiation dose

1 This category is unlikely in the event of a radiological dispersal device ("dirty bomb") but may occur in the event of a nuclear attack or when exposed to a high-activity radioactive source
2 Vomiting may be due to reasons other than radiation exposure (medical, psychological, trauma)
3 If vomiting only occurs once, is probably not radiation-induced
4 Perform dose assessment, consider observation, CBC series if rad. exposure is likely
5 Treat minor injuries

Class 3: External contamination, no significant injury, possible significant radiation dose

1 High radiation dose most likely to those nearest event. In event of RDD attack, these victims will likely also have physical injuries
2 Decontaminate patients if possible, or implement contamination controls
3 Treat minor injuries and other illness as appropriate
4 If contamination is found around nose, mouth, or open wounds, consider potential for internal contamination and sample if possible using
5 Bilateral nasal swabs
6 Bioassay (urine, fecal, blood)
7 Consult with radiation medical expert, health physicist, DOHMH, etc. regarding need for bioassay and appropriate collection protocol
8 If radiation exposure estimate is 100-200 rad, admit to hospital for observation and serial CBCs
9 Consult with health physicist, radiation oncologist, radiation medicine expert for further evaluation and dose reconstruction

Class 4: No external contamination, significant injury, no significant radiation dose (trauma may occur when fleeing site of event)

1 Treat injuries and trauma
2 Consider psychological and social needs of victim, family, and friends

Class 5: External contamination, significant injury, no significant radiation dose

1 Stabilize serious injuries and trauma first
2 Decontaminate when patient is stable, follow contamination control measures
3 Consider psychological and social needs of victim, family, and friends. Assure patients that contamination is not a significant health problem
4 If contamination is found around nose, mouth, or open wounds, consider potential for internal contamination and sample if possible using
5 Bilateral nasal swabs
6 Bioassay (urine, fecal, blood)
7 Consult with radiation medical expert, health physicist, DOHMH, etc. regarding need for bioassay and appropriate collection protocol
8 Consult with health physicist, radiation oncologist, radiation medicine expert for further evaluation and dose reconstruction

Class 6: No external contamination, significant injury, possible significant radiation dose

1 This category is unlikely in the event of a radiological dispersal device ("dirty bomb") but may occur in the event of a nuclear attack or when exposed to a high-activity radioactive source
2 Vomiting may be due to reasons other than radiation exposure (medical, psychological, trauma)
3 If vomiting only occurs once, is probably not radiation-induced
4 Perform dose assessment, consider observation, CBC series if radiation exposure is likely
5 If the exposure is serious (> 100 rad), complete all surgical procedures within 2 days of exposure
6 Consult with health physicist, radiation oncologist, radiation medicine expert for further evaluation and dose reconstruction

Class 7: External contamination, significant injury, possible significant radiation exposure

1 Stabilize serious injuries first. Take appropriate contamination control actions.
2 Decontaminate patient when stable.
3 Consider psychological and social needs of victim, family, and friends. Assure patients that contamination is not a significant health problem
4 If contamination is found around nose, mouth, or open wounds, consider potential for internal contamination and sample if possible using
5 Bilateral nasal swabs
6 Bioassay (urine, fecal, blood)
7 Consult with radiation medical expert, health physicist, DOHMH, etc. regarding need for bioassay and appropriate collection protocol
8 Complete radiation dose assessment, consider observation with serial CBCs if radiation exposure is likely
9 If the exposure is serious (> 100 rad), complete all surgical procedures within 2 days of exposure

For single, acute exposure, note the time of the onset of vomiting and estimated dose range. The timeframe for onset of symptoms varies if dose rate was low (i.e., if the total exposure was spread over a longer interval of time)

Vomiting in ____ of accident	**Estimated radiation dose**
< 10 minutes	> 800 rad
10-30 minutes	600-800 rad
30-60 minutes	400-600 rad
1-2 hours	200-400 rad
> 2 hours after exposure	< 200 rad

Note: exposure to very high levels of radiation can cause unconsciousness. However, such exposures are very rare. It is more likely that a patient is unconscious due to trauma or shock.

Assessing radiation exposure in first 12 hours following a radiological event

Injury group	**Radiation dose (rad)**	**Prognosis**	**Clinical issues**
1	< 100	Survival certain	Generally asymptomatic to mild anorexia and nausea (within a few hours). No significant impairment
2	100-200	Survival probable	Mild acute radiation syndrome (ARS). Prodromal nausea and vomiting (1-2 days). Mild hematologic abnormalities with little consequent clinical impairment for at least 2-3 weeks
3	200-800	Survival possible	Classical ARS prodroma. Possible subsequent performance decrement from fatigue with major hematologic derangement and possible life-threatening complications in 2-3 weeks. Requires major supportive therapy.
4	800-3000	Survival unlikely	Accelerated severe ARS prodroma: diarrhea, weakness, and recurrent GI problems. Major hematologic complications if survival exceeds 1-2 weeks. May survive hematologic syndrome with aggressive therapy, but death usually follows due to GI syndrome or pulmonary complications
5	>3000	Survival impossible	Immediate violent ARS prodroma with disturbances in consciousness and homeostasis leading to shock, coma, and death in a few hours to a few days. Significant neurological syndrome indicates a lethal dose of radiation was received.

From Wald, N (1996): Alteration of Hematological Parameters by Radiation. Appendix B in Triage of Irradiated Personnel, AFRRI Workshop Proceedings

- ***Software-based dose estimates***

The Armed Forces Radiobiology Research Institute (AFRRI) maintains a Windows-based software package titled Biodosimetry Assessment Tool (BAT). To use this software, one must contact AFRRI via their web page (www.afrri.usuhs.mil) and request downloading information.

If use of this software is anticipated, this should be done at the earliest opportunity; this will also provide an opportunity to learn to use the program prior to an actual emergency.

- ***Hospital care by radiation injury group***

Group 1 (Mild): Nausea, vomiting, and some abnormal blood counts more than 2 days

1 Triage by prodromal syndromes and lymphocyte depletion. No hospital care necessary

Group 2 (Mild): Nausea, vomiting, and some derangement of blood count within 2 days

1 Determine radiation dose using biological dosimetry (e.g. lymphocyte depletion) or physical dosimetry (skin burns, film badges, radiation measurements, etc.)
2 Consider using chromosome bioassay (contact AFRRI for testing), however this can take 1 week or longer. Only useful for doses in excess of 200 rad.
3 Emergency surgery may be performed only in first 2 days post-exposure with immediate wound closure. If surgery not performed in first 2 days, must wait for 6 weeks because of damage to blood-forming organs (including immune system).
4 Close observation and frequent CBC with differential
5 Elevated amylase
6 Outpatient management may be possible if there are no medical complications and close follow-up is assured. This is less likely for pediatric patients due to greater radiation sensitivity.
7 Repeat CBC every 2-3 days for 4 weeks in all patients if possible
8 Perform physical examination, including noting hair loss, skin erythema, skin injury, mucositis, parotitis, weight low, appetite, or fever; document daily if hospitalized.
9 Manage residual skin contamination
10 Consider blood and tissue typing
11 Consider viral prophylaxis
12 Consult with hematologist, radiation medicine expert, AFRRI, and/or REAC/TS regarding colony stimulating factors, other treatment options, dosimetry, and prognosis

Group 3 (Moderate to Severe): Marked leukocyte and lymphocyte count derangement in 3 days

1 Immediate reverse isolation
2 Triage by prodromal symptoms and lymphocyte depletion
3 Consider using chromosome bioassay (contact AFRRI for testing), however this can take 1 week or longer.
4 Perform blood and tissue typing
5 Emergency surgery may be performed only in first 2 days post-exposure with immediate wound closure. If surgery not performed in first 2 days, must wait for 6 weeks because of damage to blood-forming organs (including immune system).
6 Perform physical examination, including noting hair loss, skin erythema, skin injury, mucositis, parotitis, weight low, appetite, or fever; document daily if hospitalized.
7 Begin immediate gut decontamination – antibiotic, antifungal, antiviral
8 Administer growth factor therapy

9 If dose is greater than 500 rem, may require transfusion of peripheral blood progenitor cells or umbilical cord/placental blood progenitor cells
10 Perform viral prophylaxis
11 Administer antibiotics for febrile neutropenia
12 Consult with hematology team with knowledge of experimental growth factor, interleukin combinations, stem cell transfusion, bone marrow transplants. Consult with REAC/TS

Group 4 (Severe): Diarrhea within 4 days, marked platelet derangement within 6-9 days

1 Survivability unlikely
2 Care for as noted above if resources are available
3 Provide comfort care only in the event of cardiovascular or neurological syndrome

Group 5 (Severe): Nausea, vomiting, diarrhea within minutes; shock, ataxia, coma, disorientation within minutes to hours

1 Survivability unlikely
2 Care for as noted above if resources are available
3 Provide comfort care only in the event of cardiovascular or neurological syndrome

Significant radiation exposure should be suspected if vomiting occurs within 6 hours after a radiation exposure.

1 Draw CBC shortly after admission, then every 6-8 hours afterwards for 48 hours post-exposure. Pay attention to lymphocyte depletion, which may indicate radiation injury. Compare to Andrews curve (first page of this section). If lymphocyte counts do not change significantly, vomiting is not due to radiation exposure
2 If lymphocyte count is dropping, continue CBCs and treat and/or hospitalize as appropriate (see following section)
3 If admitted to hospital, perform frequent physical exams for first 3 days. Note exact time of onset for clinical symptoms, particularly nausea, vomiting, diarrhea, fever, itching, skin reddening, blistering.

Effects of exposure to various levels of acute radiation

Dose of 0-0.75 Gy (0-75 rad) in air																				
	Time post-exposure																			
Symptoms	Hours							Days							Weeks					
	0	4	8	12	16	20	24	1	2	3	4	5	6	7	1	2	3	4	5	6
Nausea Vomiting/retching Anorexia Diarrhea/cramps	0-5% mild																			
Fatigue Weakness																				
Hypotension Dizziness Disorientation																				
Bleeding Fever Infection Ulceration																				
Fluid loss/electrolyte imbalance Headache Fainting Prostration																				
Death																				
Medical treatment	Reassurance, counseling																			
Clinical remarks	Possible anxiety, possible mild lymphocyte depression in 24 hrs																			

Dose of 0.75-1.5 Gy (75-150 rad) in air																				
	Time post-exposure																			
Symptoms	Hours							Days							Weeks					
	0	4	8	12	16	20	24	1	2	3	4	5	6	7	1	2	3	4	5	6
Nausea Vomiting/retching Anorexia Diarrhea/cramps	5-30% mild 5-20% mild 15-50% mild																			
Fatigue Weakness																				
Hypotension Dizziness Disorientation																				
Bleeding Fever Infection Ulceration								A B							A					
Fluid loss/electrolyte imbalance Headache Fainting Prostration																				
Death																				
Medical treatment	Debridement and primary closure of wounds, no surgery delay																			
Clinical remarks	A. Moderate drop in lymphocyte, platelet, granulocyte counts B. Increased susceptibility to non-opportunistic pathogens																			

Dose of 1.5 - 3.0 Gy (150-300 rad) in air

Symptoms	Time post-exposure: Hours 0 4 8 12 16 20 24	Days 1 2 3 4 5 6 7	Weeks 1 2 3 4 5 6
Nausea	30-70% mild-moderate		
Vomiting/retching	20-70% mild-moderate		
Anorexia	50-90%		
Diarrhea/cramps			
Fatigue	30-60% mild-moderate	mild	
Weakness	30-60% mild-moderate	mild	
Hypotension			
Dizziness			
Disorientation			
Bleeding			A 10% mild
Fever			
Infection			B 10-50%
Ulceration		C	
Fluid loss/electrolyte imbalance			
Headache			
Fainting			
Prostration			
Death			<5%
Medical treatment	Fluid, electrolytes for GI losses, cytokines for immune compromised		
Clinical remarks	A. Drop in platelets from 3 to 0.8-1.8 x10^5 per mm^3		
	B. Drop in granulocytes from 6 to 2.0-4.5 x 10^3 per mm^3		
	C. Drop in lymphocytes from 3 to 1.0-2.0 x10^3 per mm^3		

Dose of 3.0 to 5.3 Gy (300 to 530 rad) in air

Symptoms	Time post-exposure: Hours 0 4 8 12 16 20 24	Days 1 2 3 4 5 6 7	Weeks 1 2 3 4 5 6
Nausea	70-90% moderate		
Vomiting/retching	0-80% moderate		
Anorexia	90-100% severe		60%
Diarrhea/cramps	10% moderate		40-60%
Fatigue	60-90% moderate	mild	moderate
Weakness	60-90% moderate	mild	moderate
Hypotension			
Dizziness			
Disorientation			
Bleeding		A 0-50% moderate	
Fever		B	
Infection		C 80% moderate	
Ulceration			D 30% mod.
Fluid loss/electrolyte imbalance			
Headache			
Fainting			
Prostration			
Death			5-50%
Medical treatment	Fluid, electrolytes for GI losses, cytokines, specific antibiotics		
Clinical remarks	A. Drop in platelets from 3 to 0.1-0.8 x10^5 per mm^3		
	B. Drop in granulocytes from 6 to 0.5-2.0 x 10^3 per mm^3		
	C. Drop in lymphocytes from 3 to 0.4-1.0 x10^3 per mm^3		
	D. Possible epilation		

Dose of 5.3 to 8.3 Gray (530-830 rad) in air																								
	Time post-exposure																							
Symptoms	Hours								Days							Weeks								
	0	4	8	12	16	20	24		1	2	3	4	5	6	7	1	2	3	4	5	6			
Nausea	90-100% mod - severe																	60-100%						
Vomiting/retching	80-100% mod-severe																	severe						
Anorexia	100%																		100%					
Diarrhea/cramps	10% moderate to severe															60-100% severe								
Fatigue			90-100% moderate to severe																					
Weakness			90-100% moderate to severe																					
Hypotension																								
Dizziness																		60% moderate						
Disorientation																		60% moderate						
Bleeding																A 50-100% mod-sev								
Fever															B 60-100% mod-severe									
Infection														C										
Ulceration																	D 50% mild-mod							
Fluid loss/electrolyte imbalance			40% mild to moderate																E 30%					
Headache			50% mild-moderate																50%					
Fainting																			50%					
Prostration																			60%					
Death																			50-99%					
Medical treatment	Tertiary level intensive care, cytokines, fluids, antibiotics, GI decon																							
Clinical remarks	A. Severe platelet drop to 0.0-0.1 x10^5 per mm^3																							
	B. Severe granulocyte drop to 0.0-0.5 x10^3 per mm^3																							
Complete surgery 36-48 hrs, or wait for 6 weeks	C. Severe lymphocyte drop 0.0-0.1 x10^5 per mm^3																							
	D. Epilation								E. Mild intestinal damage															

Dose of 8.3 to 11 Gy (830-1100 rad) in air																								
	Time post-exposure																							
Symptoms	Hours								Days							Weeks								
	0	4	8	12	16	20	24		1	2	3	4	5	6	7	1	2	3	4	5	6			
Nausea	100% moderate to severe															100%								
Vomiting/retching	100% moderate to severe																100%							
Anorexia	100%														100%									
Diarrhea/cramps	10% moderate to severe														100% moderate to severe									
Fatigue																								
Weakness																								
Hypotension																100% severe								
Dizziness	100% severe															100% severe								
Disorientation	100% severe															100% severe								
Bleeding															A 100% severe									
Fever															B 100% severe									
Infection														C										
Ulceration															D 100% severe									
Fluid loss/electrolyte imbalance			80% moderate													E 80% severe								
Headache			80% moderate												100% severe									
Fainting																								
Prostration															80% mod to severe									
Death																	100%							
Medical treatment	Supportive therapy, aggressive therapy if evidence of response																							
Clinical remarks	A. Platelet count drops to nearly 0																							
	B. Granulocyte count drops to nearly 0																							
Bone marrow totally depleted	C. Lymphocyte count drops to nearly 0																							
	D. Epilation								E. Moderate intestinal damage															

Dose 11-15 Gray (1100-1500 rad) in air																				
	Time post-exposure																			
Symptoms	Hours								Days							Weeks					
	0	4	8	12	16	20	24		1	2	3	4	5	6	7	1	2	3	4	5	6
Nausea	100% severe												100% moderate-severe								
Vomiting/retching	100% severe															100% mod-severe					
Anorexia	100% severe												100% severe								
Diarrhea/cramps		10% severe											100% severe								
Fatigue	100% severe																				
Weakness	100% severe																				
Hypotension		A 80% mild												100% severe							
Dizziness	100% severe															100% severe					
Disorientation	100% severe															100% severe					
Bleeding																B 100% severe					
Fever												B 100% severe									
Infection											B										
Ulceration													C 100% severe								
Fluid loss/electrolyte imbalance		100% moderate to severe										D 100% severe									
Headache		100% moderate to severe											100% severe								
Fainting													70% mod-severe								
Prostration													70% mod-severe								
Death									100%												
Medical treatment	Bone marrow totally depleted, tertiary care may help somewhat																				
Clinical remarks	A. Blood press drops 25%, temp increases to 102 F																				
	B. Platelet, lymphocyte, granulocyte counts drop to 0																				
	C. Epilation D. Moderate to severe intestinal damage																				

Dose of 15-30 Gray (1500-3000 rad) in air																				
	Time post-exposure																			
Symptoms	Hours								Days							Weeks					
	0	4	8	12	16	20	24		1	2	3	4	5	6	7	1	2	3	4	5	6
Nausea	100% severe											100% severe									
Vomiting/retching	100% severe												100% severe								
Anorexia	100% severe												100% severe								
Diarrhea/cramps		20% severe											100% severe								
Fatigue	100% severe																				
Weakness	100% severe																				
Hypotension	100% moderate to severe																				
Dizziness	100% severe																				
Disorientation	100% severe																				
Bleeding														A 100% severe							
Fever	45-80% mod-severe												A 100% severe								
Infection												A									
Ulceration														100% severe							
Fluid loss/electrolyte imbalance																					
Headache																					
Fainting																					
Prostration																					
Death																					
Medical treatment	Supportive therapy																				
Clinical remarks	A Platelet, granulocyte, lymphocyte counts drop to 0																				
	B Severe intestinal damage																				
Bone marrow completely depleted within days.	C Renal failure																				

Radiological Incidents and Emergencies

Radiological incidents and emergencies are any such events involving exposure of patients and/or emergency workers to radiation or radioactivity. A radiological incident is any instance in which people or the environment are exposed to radiation or radioactivity through accident or misuse (including deliberate misuse). A radiological emergency is any radiological incident in which there is the risk of injury or death, even if that risk is not from the radiation itself. For example, exploding a radiological dispersal device (RDD, colloquially called a "dirty bomb") will not cause radiation injury, but the blast may place lives at risk. Attack with an RDD, then, is a radiological emergency even though you will not expect to see any patients with radiation-caused injuries. Some examples of radiological incidents and emergencies are:

1. Traffic accident involving a truck carrying research or medical radioactive isotopes
2. Terrorist attack with RDDs
3. Fire in a hospital or university radioactive waste storage facility
4. Unplanned radioactive release from a commercial nuclear power station
5. Detonation of a nuclear weapon
6. Loss of a radioactive soil density gauge or well logging gauge
7. Accidental exposure of a maintenance technician to radiation from an industrial linear accelerator
8. Radiation burns to the fingers from the beam of an x-ray diffractometer in a soil science laboratory
9. Accidental overexposure to an angiography patient from excessive fluoroscopy, resulting in radiation burns to the skin
10. Spill of radioactive liquids in a research laboratory

The public, emergency responders, and medical personnel often respond inappropriately to radiological incidents and emergencies, owing to widespread misunderstanding the risks posed by radiation and radioactivity. In particular, members of the public often panic and tend to attribute all real and perceived health problems to the effects of radiation. Emergency response personnel sometimes hesitate to approach the scene of radiological incidents, and medical personnel frequently delay or deny treatment to contaminated or irradiated patients. In addition, there are many instances in which medical personnel have failed to diagnose exposure to radiation, providing inappropriate medical care. Medical personnel must be able to recognize radiation injury and to provide appropriate medical assistance to personnel at the scene and in the hospital to all patients involved in radiological incidents and emergencies.

➢ *On-scene medical assistance*

Medical personnel at the incident scene may be called upon to treat or triage patients suffering from the effects of exposure to high levels of radiation or to treat or triage patients contaminated with radioactivity.

➢ *Caring for patients exposed to high levels of radiation*

Patients exposed to moderately high levels of radiation (100 rem or less) will likely exhibit no symptoms of radiation sickness while at the scene. Laboratory work will show a depression in

red and white blood cells, but this may not appear for several days after the exposure. About 10% of patients exposed to 100 rem will exhibit mild radiation sickness, but may not attribute it to radiation exposure.

Patients exposed to higher levels of radiation will experience more severe radiation sickness that will appear more rapidly. A patient receiving a dose of 450 rads has a 50% chance of death without medical intervention, primarily due to radiation-induced immune system suppression and subsequent infectious disease. With medical support, such patients are likely to survive exposure. These patients will also experience radiation sickness. However, if radiation sickness appears within 30 to 60 minutes after exposure, the patient has likely received a fatal dose of radiation. Such patients should be made as comfortable as possible.

Some patients may be exposed to high levels of radiation that affect only a part of their bodies. For example, a scientist who places his or her fingers into the beam of an x-ray diffractometer may have very severe burns on the exposed fingers, but no other symptoms. In such cases, it may be necessary to perform skin grafts or even to amputate the fingers or hand but the rest of the body will remain unaffected. Similarly, personnel may have "hot" particles fall onto their skin, giving severe radiation burns to very small areas. These patients must be decontaminated and the burns dressed at the scene, and skin grafts may be required after admission to the hospital.

Differentiating between radiation burns and thermal burns can be difficult, and it is not always possible to make this distinction based solely on clinical evidence. Most radiation burns will lead to erythema, blistering, and other tissue damage, but so do many thermal burns and serious sunburn. In some cases, the patient will be able to provide helpful information – they may recall recent radiology or radiation oncology procedures or may mention that they work in a facility with radiation-generating equipment for example. Medical staff should also know that radiation injury is seldom, if ever associated with charring, so charred tissue is almost always a sign of thermal injury.

However, patients near the site of a dirty bomb explosion may suffer thermal burns from the chemical explosion and be radioactively contaminated. Remember that exposure to radiation does not cause a person to become radioactive – if you survey a patient and find positive counts with a radiation instrument, chances are that the burns are thermal burns, not radiation burns.

There is little or no health risk to medical or emergency personnel from working with patients exposed to high levels of radiation provided they take appropriate precautions, such as those outlined in this section. Irradiated patients do not become radioactive.

Clinical signs of radiation exposure

1. Nausea and vomiting (prodromal syndrome – if experienced shortly after exposure the patient has probably received a lethal radiation dose)
2. Possible erythema when patient denies thermal or chemical exposure (may be localized, depending on source of radiation

3 Blistering, ulcerated tissue, possible necrosis (following exposure to very high, localized exposure to radiation)
4 Depression in red and white blood cell counts (usually occurs a few to several weeks after exposure)
5 Elevated levels of chromosomal aberrations

Treatment for patients exposed to high levels of whole-body radiation

Patients exhibiting signs of radiation sickness immediately after an accident have likely received a fatal dose of radiation. Treating their symptoms will help to make them comfortable until a physician specializing in such cases can be contacted for the most recent medical advice. Such advice is available from the REACTS center at the Oak Ridge National Laboratory
Patients receiving several hundred rem of exposure will exhibit reduced immune system function. Such patients require medical support until their immune systems can recover.

➢ *Caring for radioactively contaminated patients*

Patients contaminated, even at very high levels, pose no threat to emergency response or medical personnel. Simple precautions, such as wearing latex gloves and a nuisance mask, changing outer clothing, and washing or showering after patient contact will suffice to protect medical staff. However, even if such measures are not immediately possible, radioactive contamination does not pose a health risk to emergency responders or medical staff. It is imperative that medical staff treat significant medical problems with whatever degree of urgency is required. If a patient is only slightly injured, it may be appropriate to attempt decontamination before treating the patient, just as a physician will clean a laceration prior to suturing. However, serious injury requires immediate medical care that must be provided by the medical staff – decontaminating staff, equipment, or facilities (including ambulances) can be performed by health physics personnel after the incident is resolved.

Contaminated patients should be transported along a dedicated route, preferably lined with plastic sheeting, to minimize the spread of contamination through the medical facility. Only contaminated patients or properly garbed workers (e.g. wearing the PPE outlined in the next section) should be permitted to use the contamination control pathway when it is established.

There are several possible scenarios when working with contaminated patients: patients with contaminated skin but uncontaminated wounds, patients with contaminated wounds, patients with internal contamination, patients with contaminated material embedded in their bodies. These are described below.

➢ *Patients with contaminated skin but uncontaminated wounds*

1. Perform radiation survey to confirm that the wound(s) are not contaminated
2. Treat the wound as appropriate and cover with waterproof dressing
3. When time permits, decontaminate patient with damp towels or sponges, treating materials used as radioactive waste when finished
4. Patients with contaminated wounds
5. Assume that a contaminated wound will lead to internal contamination

6. If isotope has been identified, consult with health physicist if available for isotope-specific information
7. Drape wound with waterproof material to limit spread of radioactive materials
8. Monitor wound, using wound probe if available, prior to irrigation
9. Gently irrigate with sterile saline; multiple irrigations may be required
10. Following irrigation, remove drapes and dressings and monitor wound
11. If contamination levels are still more than twice background readings, re-drape wound and re-irrigate.
12. If repeated irrigation does not reduce contamination levels sufficiently, consider debridement. Vital tissues should not be excised without expert medical advice is obtained unless absolutely necessary.
13. Tissue that has been removed should be retained for health physics assessment
14. Remove visible radioactive particles with long forceps or water pik. Do not handle radioactive particles with hands.
15. After decontamination, the wound should be covered with a waterproof dressing. If sutures are needed, surrounding skin should be decontaminated prior to suturing.

- ***Patients with embedded contaminated materials***

1. Treat contaminated wound as noted above.
2. Identify foreign objects visually. If possible, attempt to use radiation detector to confirm they are radioactive. Objects with the highest readings should be removed before mildly radioactive particles. However, objects that pose the greatest medical risk must take priority over others.
3. Remove foreign objects using forceps, water pik, or other similar means. Radioactive objects should not be handled with the hands unless it is absolutely necessary.
4. Irrigate the wound following removal of the object(s). Survey to confirm all radioactivity has been removed.
5. Decontaminate surrounding skin and suture as necessary, then cover with a waterproof dressing.

- ***Patients with internal contamination***

1. Internal contamination should be suspected if the patient was exposed to a radioactive cloud or if there is extensive contamination around the mouth and/or nose or if there are contaminated wounds
2. If the patient has ingested minor amounts of radioactive materials, or if the patient's condition will not permit further actions, monitor the patient's condition during recovery
3. If the patient has ingested large quantities of radioactive materials, consider taking actions to remove contamination from the body. This may include gastric lavage, emetics, etc. Attempt to contact a medical expert prior to taking these actions.
4. If the patient has inhaled radioactive materials (as indicated by elevated readings around the nose or mouth), try to determine the amount inhaled
5. Gamma-emitting isotopes will produce elevated count rates on the outside of the chest.
6. Alpha and beta-emitting isotopes are not detectable from outside the body, but may appear in mucus, nasal hairs, etc.

7. Such swabs or samples should be counted by radiation safety personnel (if available) with a Geiger counter or in a liquid scintillation counter
8. If it appears that there has been an uptake of radioactive materials, consult with an expert before attempting treatment. Sources of information include the Radiation Emergency Assistance Center/Training Site (REAC/TS) from their web site at www.orau.gov/reacts/.

➢ *Personal protective equipment (PPE) when working with contaminated patients*

Medical personnel working with patients contaminated with radioactivity should wear the following PPE:

1. two sets of latex gloves
2. N-95 mask or equivalent respiratory protection
3. disposal shoe covers
4. outer coverall garment such as a "bunny suit" or surgical scrubs

Sequence for donning PPE

1. Surgical gown and trousers (or coverall – "bunny suit")
2. Shoe covers – tape tops of shoe covers over bottom of coverall leg
3. Head/hair cover and N-95 mask
4. Double gloves – tape outer gloves over cuff of coverall

Sequence for removing PPE

1. Remove outer gloves first, turning them inside-out as they are pulled off.
2. Give dosimeter to radiation safety technician (if available).
3. Remove all tape at trouser cuffs and sleeves.
4. Remove outer surgical gown, turning it inside-out -- avoid shaking the gown.
5. Pull surgical trousers off over shoe covers.
6. Remove head cover and mask.
7. Remove shoe cover from one foot and let radiation safety technician (if available) monitor shoe; if shoe is clean, step over control line, then remove other shoe cover and monitor other shoe.
8. Remove inner gloves.
9. Do total-body radiological survey
10. Take shower if time permits; at the least, shower at the end of the shift, prior to leaving your work area.

After staff exit, the decontamination room should be secured and a sign reading "CAUTION -- CONTROLLED AREA -- DO NOT ENTER" should be posted. Unless it is needed for emergency medical reasons, the decontamination room remains secured until it can be checked and decontaminated, if necessary, by the radiation safety officer or other health physics expert.

Radiological control methods

➢ *Patient decontamination*

1. Remove patient's clothing, dress in hospital scrubs or patient gown
2. Rinse contaminated areas with saline solution or de-ionized water
3. Shower or bathe patient, using mild soap and cool to warm water
4. Give sponge bath, discard sponge or washcloth as radioactive waste
5. Flush open wounds with saline solution or de-ionized water
6. Use standard sterile practices prior to administering injections, suturing, or other practices that puncture or break the skin

➢ *Emergency room contamination control*

1. Wrap patient in blankets to contain contamination and reduce contamination of facilities
2. Establish dedicated routes for transporting contaminated patients
3. Establish dedicated rooms for decontamination and care of contaminated patients
4. Line dedicated routes and rooms with plastic to reduce contamination of fixed surfaces
5. Do not use rooms for non-contaminated patients until checked and released by Radiation Safety personnel

➢ *Medical staff contamination control*

1. Follow universal precautions – wear gloves, lab coats, shoe covers etc. to reduce personnel contamination and to cover all exposed skin to the maximum extent possible
2. Wear surgical masks to reduce chance of inhaling contamination
3. Securely bandage or cover all open cuts, scrapes, and other wounds
4. Change gloves after each patient
5. Remove shoe covers prior to leaving any contaminated area
6. Wash hands and exposed skin thoroughly after each patient
7. Change clothes and shower at the end of the shift or when leaving patient decontamination or treatment areas
8. Medical personnel working with highly contaminated patients should consider performing a urine bioassay 24-72 hours after exposure to check for evidence of radionuclide uptake. About 20 ml of urine is required, of which 1 ml will be counted in a liquid scintillation counter.

➢ *Emergency care for badly injured, contaminated patients*

1. If the patient requires immediate attention, treat the patient first and worry about radiological controls when the patient's condition has stabilized. Rooms and medical staff can be decontaminated later.
2. Even badly-contaminated patients pose no health risk to medical or emergency personnel

➢ *If radiation safety personnel are present they should:*

1. Survey all patients prior to their entry into medical facilities

2. Assist with patient decontamination when practicable
3. Assist with establishing controlled areas for patient transport and treatment
4. Survey controlled areas periodically to determine necessity for replacing or renewing coverings
5. Establish and perform confirmation surveys of boundaries delineating controlled areas
6. Survey medical and emergency personnel prior to exiting from controlled areas
7. Perform bioassay measurements as necessary (probably at end of shift or the following day) to determine uptake of radionuclides by medical and emergency response personnel
8. Perform bioassay measurements as necessary for patients thought to have been exposed to radioactive contamination
9. Identify contaminating isotope(s)

Addressing minor radiological incidents

➢ *General guidelines*

In most cases, radiological incidents are not life-threatening and, in fact, pose little actual physical risk. The radioactivity is a nuisance, a regulatory problem, and a complicating factor, but it is rarely potentially harmful. So the first general rule should be "Don't panic." Take the opportunity to think through your actions before springing into action to try to save the day. By so doing, you are less likely to take rash actions that could well end up making things worse rather than better.

In general, radiological hazards will pose little risk to people involved in a radiological accident. This means that emergency responders and medical personnel are very unlikely to be at risk from victims or patients, no matter how heavily contaminated they are. This means that victims and patients should be cared for as rapidly as required by their injuries – the badly injured or critical should be cared for immediately, and lightly injured patients may be safely decontaminated or wrapped to contain the contamination so that they do not contaminate an ambulance or hospital emergency room.

Actions should be taken to try to minimize exposure to people near and responding to the incident. Unless actually involved in incident response, everyone should stay at the greatest distance possible, they should minimize the amount of time they're in a controlled area, they should try to interpose shielding between themselves and the sources of radiation, and they should try to don appropriate PPE (such as shoe covers, gloves, and coveralls when involved in a spill) if possible.

➢ *Spill of radioactive material*

It is inevitable that, in the course of working with radioactively contaminated patients, there will be the spread of contamination and/or spills of radioactive materials. However, though this may be inconvenient, it is not an emergency, and most spills can be addressed without excessive difficulty. It is also worth noting that spills and contamination incidents are hardly unusual in a medical setting; every hospital with a nuclear medicine department has undoubtedly experienced

a radioactive spill at some point, and nuclear medicine technologists are often skilled at dealing with spills of radioactive materials.

It's easy to cause a spill – knocking over a small vial of radioactive materials can cause one, as can accidentally ejecting the contents of a pipettor or dropping a sample tube or even just having a drop fall from a beaker or bottle. Radioactive spills cause contamination in the area of the spill, they can lead to the contamination of personnel, and they can result in the spread of contamination to office areas or homes. Minor spills can often be cleaned up fairly easily; major spills can cause problems.

There are some actions that can be taken immediately in the event of a spill. A useful acronym to remember is SWIM – Stop the spill, Warn others of the spill, Isolate the area, and Minimize exposure to radiation. It is not necessary to follow these steps in this order, but completing these actions will help to reduce the impact of the event.

Stopping the spill is not the same as cleaning it up; it is taking actions to keep the spill from getting worse. If a container fell over, right it (wearing protective gloves, hopefully!) cap or cover it, and place it in a pail or deep tray. Next, try to place absorbent materials over the spilled liquid or, if it is a powder, cover it with dampened wipes or rags to keep it from blowing around. You are not trying to clean up the spill at this point, you are simply trying to limit the amount of spilled material and its extent.

Warning others may be the first thing that happens – most people make some comment when they cause a spill. You will want to warn others not to walk into the spill area, to ask for help with the cleanup, and anyone nearby who might have been contaminated by the spill should stand fast to keep them from spreading contamination. This should also include contacting the radiation safety officer and other radiation safety staff, plus anyone else on your incident call-up list. Workers should be able to contact the RSO or a competent alternative at any time in the event of a radiological incident, so the RSO's pager and/or telephone number(s) should be made available to radiation workers or to Security officers as appropriate in the event of after-hours spills.

Isolate the area involved in the spill. There are several reasons to do this; you want to keep people out of the spill so they don't get contaminated, you will need room to work on cleaning up the spill, and anyone within the spill boundaries should be considered potentially contaminated. You should use rope or tape or some other physical barrier whenever possible, even if you are isolating an entire room. Simply posting a door sign may not work – many people just don't read door signs – but they will stop before crossing a rope or tape boundary. Nobody should be permitted to cross a spill boundary to enter an area unless they are wearing gloves, shoe covers, and a lab coat; and nobody should exit a spill area unless they are surveyed out of the area by someone competent to do so. Once spill boundaries are established, they should be verified by surveying on the "clean" side to confirm that all of the contamination is contained within the boundaries.

Minimizing exposure is as much a philosophical point as a procedure. As noted above, spills are not life-endangering. There is time to consider the best way to address the problem. Think

about the situation you are faced with – do you have proper PPE, do you have the materials you need to survey and decontaminated efficiently, are you wearing respiratory protection (if the materials are volatile), do you have dosimetry, do you know where the highest radiation areas are (and how to work around them), and so forth. By taking a moment to consider your situation and planning on how to best address it, you will be helping to reduce your exposure and that of others in the area.

➢ *Decontamination or contamination controls*

Following a radioactive spill, some level of contamination controls will have to be used to reduce the spread of contamination. Such controls may simply take the form of covering the contaminated area with a sheet of plastic, or taking up contaminated plastic sheeting already installed. This is certainly the simplest and quickest approach, although it only defers the need to decontaminate until a later time.

Decontaminating a surface is not complicated, but it can be time-consuming. In general, it is best to start by using absorbent materials to soak up contaminated liquids, or by using damp absorbent materials (e.g. paper towels) to wipe up contaminated powders.

When engaged in the midst of an emergency, it is probably best to take actions that will accomplish as much as possible in the shortest time. If radiation safety personnel are present, decontamination should be left to them as much as possible.
In general, it is better to work from the outer spill areas towards the center and, in the case of multi-level spills (say, a spill on a table that drips to the floor) to work from the top towards the bottom. In most cases, spills may be cleaned up with standard commercial cleaners, although spills involving radioactive metals (such as Cs-137 or Co-60) may benefit from the use of specialty products such as RadiacWash, IsoClean, or CountsOff.

Contamination surveys should be performed with an appropriate detector for the type of radiation emitted by the isotope spilled. This information is summarized in the accompanying table. A direct frisk will reveal the total amount (fixed plus removable) of contamination present in an area while a smear wipe will only show how much removable contamination is there, so there is a value in performing both types of surveys. However, some isotopes (H-3, in particular) are very difficult to survey for by direct frisk and it's possible that the only reliable information about contamination levels will be obtained via smear wipe surveys.

➢ *Skin contamination*

As with radioactive spills, skin contamination is not life-endangering although, in rare cases, localized skin burns can result from "hot particles". This means that workers shouldn't panic over skin contamination, but also that they should work quickly to remove the contaminants. The immediate actions in case of skin contamination can be remembered as "CCC":

- Contact the RSO to inform him/her about the skin contamination

- Count the amount of contamination on the skin with an appropriate detector and write this number down. This will later be used to help calculate skin dose and/or possible uptake from the contamination
- Clean the contaminated area by going to the nearest sink and washing with mild soap and cool to warm water. While cleaning, a general rule is to not take any actions that are painful or uncomfortable – in most cases, the skin acts as a barrier to keep contamination on the outside of the body, and it is important to not breach this barrier.

While decontaminating, the worker should survey periodically; if the count rate continues to decrease then the decontamination is having an effect and should continue. If, however, the count rate stabilizes or if the skin starts to redden or bleed, decontamination should stop until the RSO or another qualified person arrives to determine what should be done. In some cases, simply wrapping the contaminated area in plastic can help – the contamination is "sweated" out – but this is obviously not a good idea for facial contamination! More drastic decontamination measures should ONLY be taken if there is a need (because of very high contamination levels) AND if advised by a competent radiation safety professional.

Following decontamination it may be necessary to calculate radiation dose to the skin or to internal organs. These should be done by either a staff health physicist or by a consultant because these calculations can be complex and it is necessary to make sure they are done correctly. There are some software programs that will help with these calculations, but they give the best results in the hands of a radiation safety professional. In the event a person is contaminated by something that will be absorbed through the skin (e.g. tritiated water or many iodine compounds) it may also be necessary to take urine samples or to perform thyroid counts to check for uptake of isotope. This determination can also be made by a health physicist.

Traffic accidents involving radioactive materials

Every day, radioactive materials are transported in thousands of vehicles. These include soil density gauges, radiopharmaceuticals, small vials of research isotopes, radioactive waste, nuclear reactor fuel, and more. Although rare, these vehicles are sometimes involved in accidents that may or may not release radioactive materials. It is imperative that any vehicular accident involving radioactivity be reported immediately to the company (if appropriate) and to emergency response personnel so that injured people can be cared for and so that the radioactive materials can be recovered and contained.

The primary concern for any vehicular accident is the health of the people involved in the accident. Injured personnel must be cared for first, and stabilized if necessary. Contaminated (or potentially contaminated) people should be cared for without regard to their contamination if necessary. However, it may be prudent to inform emergency response and medical personnel of the contamination (and that it poses no risk to them) so that the victim can be wrapped or decontaminated to minimize contamination spread to the ambulance or medical facility. Even this step is not a necessity, but it will help to reduce the chance that a vehicle or medical room will require decontamination prior to use for other patients.

After injured personnel are cared for, the radioactive materials must be accounted for, contained, and recovered as appropriate. The physical form of the radioactive materials (e.g. liquid, gas, solid), the manner in which they are contained, and the severity of the accident will determine the amount and spread of contamination. For example, a soil density gauge packed in its case will likely escape unscathed from all but the most severe accidents, while a jug of radioactive liquid may contaminate the inside of the vehicle and the ground it drips onto. This phase of the accident recovery should include donning appropriate protective equipment (say, gloves, protective coveralls, and shoe covers), opening the storage area, and assessing the physical condition of the radioactive materials storage container. If there is obvious leakage into the vehicle interior or onto the ground, or if contamination surveys show materials were released, they must be contained and cleaned up as necessary.

Radiological terrorism; general guidelines

Several organizations have established some general guidelines for responding to radiological attacks should your facility be involved directly. Some or all may be applicable to your facility.

1. Personnel who can neither hear nor see an explosion are probably not at risk. They should stay put if indoors or, if outdoors, go inside to await further information and instructions. People should NOT try to drive away because driving is likely to be more dangerous than staying put.
2. Many people are likely to think themselves at risk, even if they are not exposed to radiation or radioactivity. These may include those who can see smoke from the explosion, those who are downwind (even if out of range of a plume), or those who feel ill from stress or shock. Hospital personnel may need to address the concerns of these "worried well" in addition to the health risks to injured or irradiated victims.
3. After going indoors, personnel should close open doors and windows, wash hands and face (take a shower if possible), and change your outer clothes if you can.
4. Contaminated injured people should have serious injuries treated without regard to contamination levels – contaminated persons do not endanger emergency response or medical personnel. If injuries are not serious, it may be possible to decontaminate the victims before transporting them, or at least to wrap them in a sheet or blanket to minimize the spread of contamination to vehicles and hospitals. This judgment call must be made on a case-by-case basis, depending on the extent of injuries and contamination.
5. You may need to perform surveys to establish radiological boundaries. These boundaries may be for high radiation or high contamination levels. According to regulations, the limit for removable contamination in an unrestricted area is 1000 dpm/100 cm^2 and radiation levels in uncontrolled areas cannot exceed 2 mrem in one hour. Radiation surveys are relatively easy to perform, and radiation boundaries can often be established fairly easily. However, contamination boundaries are more difficult to establish because contamination surveys can be difficult and time-consuming to perform. In some cases, it may be best to simply set contamination control boundaries a few hundred meters downwind and then expand or collapse them as you survey to confirm them. Note: Until you have a good idea of contamination levels, you should dress in contamination control

gear (shoe covers, gloves, coveralls, for example) to reduce the risk of personnel contamination.

6. Potentially contaminated people should stay in the controlled area until they can be surveyed and released. If there are only a few people, it may be possible to survey everyone directly and decontaminate them as necessary. However, even a few tens of people who are contaminated can take a great deal of time to survey thoroughly and decontaminate. Depending on your capabilities and those of the emergency responders, you may have little option other than releasing moderately contaminated people with instructions on how to decontaminate themselves and their clothing. However, releasing such people should be a last resort, to be taken only when it is obvious that no other reasonable options exist and with the concurrence of regulatory and emergency response personnel.
7. Eating, drinking, smoking, chewing tobacco, applying cosmetics, and other possible avenues of accidental ingestion or inhalation should be prohibited in any radiologically controlled area, or by any potentially contaminated person.

How to choose a survey meter

Type of radiation emitted	Example isotopes	Type of survey	Type of detector to use
Alpha	U-238, Pu-238, Pu-239, Ra-226, Po-210, Am-241	Direct frisk, smear wipe	Zinc sulfide (ZnS) or proportional counter
Low-energy beta	H-3, C-14, S-35, Pu-241	Smear wipe	Liquid scintillation counter, proportional counter
Medium to high-energy beta	P-32, Sr-90, I-131	Direct frisk, smear wipe	Geiger counter, liquid scintillation counter, proportional counter
Low-energy gamma	I-125, I-129, Am-241	Direct frisk or smear wipe	Thin-crystal (1”x1mm) sodium iodide
Medium- to high-energy gamma	I-131, Cs-137, Co-60, Ir-192	Direct frisk or smear wipe	Thick-crystal (1”x1” or larger) sodium iodide, Geiger counter

Chapter 5: Medical response to nuclear and radiological terrorism

(Adapted from Radiological Emergencies, in *Disaster Nursing* 2nd edition, Tener Veenema (ed.), Springer, 2006

In the event of a terrorist attack, people will suffer physical and psychological trauma. Physical effects will include the effects of exposure to any explosion – broken bones, burns, shock, lacerations, and so forth. These may be compounded by the presence of radioactive contamination and, in some cases, radiation illness. In addition, any terrorist attack will, by definition, inflict psychological trauma, and medical personnel must be prepared to receive many patients who are worried, panicked, or suffering psychosomatically in spite of being physically well. In the aftermath of a terrorist attack, even a simple headache or anxiety attack may be seen as evidence of radiation sickness.

To that end, hospitals should work to develop a plan for addressing the psychological effects of a radiological attack. This may include using checklists to help guide both medical staff and patients through the process of determining the probability of radiation exposure, using pre-printed handouts to explain to the "worried well" why they will not be admitted to the hospital, maintaining maps of areas in which radiation or contamination levels are potentially harmful, and so forth. Medical staff must be able to differentiate between real and imagined patients, and hospitals should have personnel, literature, and/or contamination/radiation maps on hand to help people understand why they were sent home instead of being treated or admitted. This may require training hospital and governmental social workers or counselors, who may be better-suited for providing this guidance to worried people.

To help determine the likelihood that a particular person might be suffering from radiation effects or contamination, medical personnel should make every effort to communicate with emergency response personnel at the scene of the attack so that area hospitals are aware of the nature of the attack (i.e nuclear weapon, radiological dispersal device, large irradiator), the highest radiation dose rates and contamination levels measured, and approximate extent of radiation or contamination. With this information, medical staff will have a rough idea, based on a patient's location at the time of the attack, as to whether the patient was likely exposed to sufficient radiation to cause various syndromes. For example, a person who is vomiting may have prodromal or gastrointestinal syndrome. However, if this person was a mile downwind of an RDD attack, this diagnosis makes no sense because they would not have been exposed to enough radiation to induce these syndromes. However, before sending such patients home, they should be radiologically surveyed to make sure they are not contaminated – a precaution that would not be necessary for a patient who was upwind at the time of the attack.

Medical response to radiological dispersion device (dirty bomb)

A radiological dispersion device (RDD or "dirty" bomb) is a chemical explosive laced with radioactivity. An RDD attack will probably lead to widespread contamination, contaminated patients and emergency responders, and victims of the blast itself, but will likely not result in

radiation injury or illness. In the case of an RDD attack, medical personnel will probably be confronted with large numbers of patients who are contaminated with radiation, some of whom may have very high contamination levels. Many more people may appear who are anxious or panicked, but not ill.

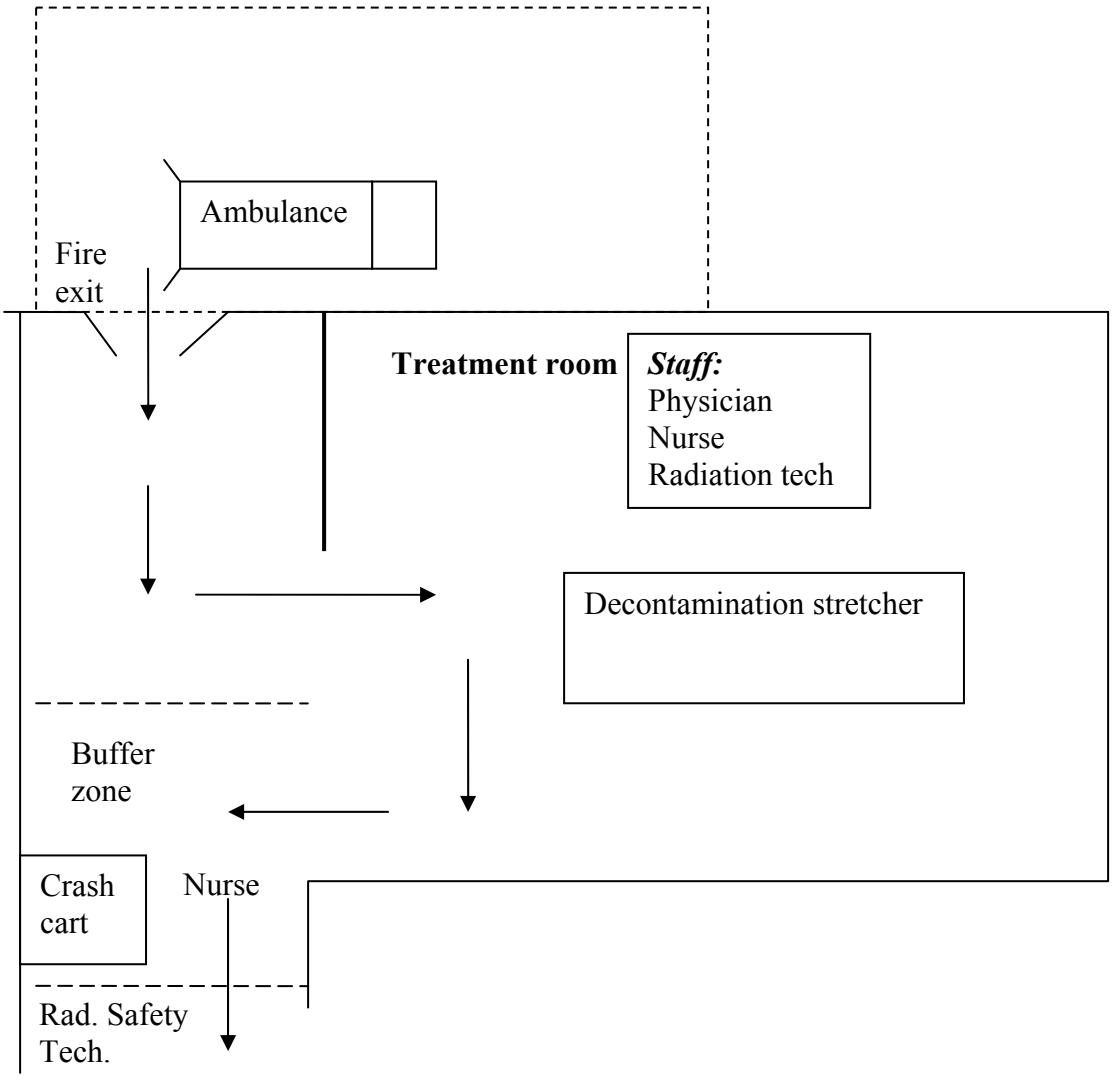
One caveat is that radioactive sources may be incorporated into an RDD, and they may survive the explosion intact. Such sources could give very high radiation doses to personnel handling them and could lead to localized radiation burns. However, in most cases, patients are expected to exhibit "normal" injuries from the explosion itself with the presence of radioactive contamination as a complicating factor.

The medical response to use of an RDD should focus on injuries from the blast – thermal burns, broken bones, shock, lacerations, internal injury, crushing, and so forth. Lightly injured patients may be decontaminated prior to arrival at the hospital, and may simply be decontaminated, treated, and released at the scene. Patients who are sent home should be instructed to change their clothes and shower when they get home. More seriously injured patients may be decontaminated prior to treating if their injuries permit – these may include patients with lacerations requiring suturing, but that are not life-threatening, or patients with sprains, contusions, or non-compound broken bones. Medical personnel must use their professional judgment in deciding how much, if any radiological controls to take. Patients with life-threatening injuries must be treated immediately, without regard to contamination levels. An alternative to decontaminating a patient is to wrap the patient in sheets, blankets, or anti-contamination clothing during transportation to the treatment room. This will help keep the patient from contaminating "clean" areas, although the treatment room will require decontamination prior to use by uncontaminated patients.

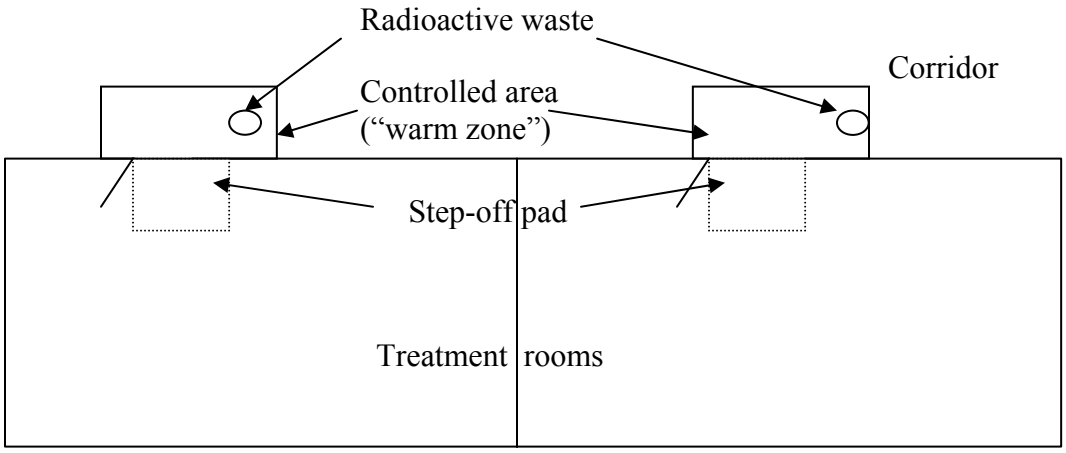
Although medical personnel may need to treat patients who are still contaminated, these patients pose no health risk to nurses or physicians. Universal precautions will serve to further reduce an already low radiation dose.

It may be helpful, weather permitting, to set up a triage and decontamination station outside of the emergency room. After the nuclear reactor accident at Three Mile Island, the local hospital established a decontamination station in their parking garage, which was better able to handle large numbers of patients. This also kept patients with imagined radiation illness from interfering with the smooth functioning of the emergency room. In the case of a radiological attack, this will also help to minimize contamination levels in the emergency room when the immediate crisis has ended.

Medical staff working with contaminated patients should wear gloves, masks, shoe covers, and lab coats or other anti-contamination clothing. They should change their clothing after each patient to reduce the chance of having skin contamination themselves, and they should change all clothes and shower after each shift. Shoe covers, gloves, masks, and anti-contamination clothing must be removed before leaving a "hot" room (a room in which a contaminated patient has been treated).



A stylized map of an emergency room set up to receive radioactively contaminated patients. Dashed and dotted lines indicate radiological boundaries.



Medical response to an irradiator attack

Instead of setting off an RDD, terrorists may simply set a high-dose irradiator in a public place. In such an attack, a relatively small number of people may suffer from radiation illness or injury (including the various syndromes or localized radiation burns if they handled the source). A larger number of people may appear at medical centers, suffering from anxiety rather than radiation sickness. Unfortunately, nausea and vomiting can result from either radiation sickness or extreme anxiety, and many patients may be unable to distinguish between the two. Although such an attack will likely injure fewer people than either an RDD or a nuclear weapon, there may still be hundreds of patients, depending on how the attack was planned and orchestrated.

Since an attack of this type will likely not be associated with an explosion, it is prudent to assume that skin burns are radiation burns and to treat them accordingly. This may include skin grafts and removal of necrotic tissue, as well as pain relief.

All patients from the site of an irradiator attack should be evaluated for radiation sickness and a health physicist or medical physicist should be consulted to attempt to determine the radiation dose to each patient. If the patient is conscious, it is essential to get as much information as possible about their exact location, travel paths, and the amount of time they spent in each place near the site of the irradiator. For example, if an irradiator is placed in an elevator, persons working on the 50th floor of a high-rise will generally receive more radiation dose than those on lower levels. On the other hand, a person who has a non-stop ride to an upper level may receive less dose than one whose trip to the tenth floor was interrupted by frequent stops. Similarly, a person walking briskly by a large source may receive far less dose than someone working at a distance of several meters.

Regardless of the severity of a patient's injuries, the patients pose absolutely no threat to medical personnel. Radiation burns from exposure to high levels of radiation are not radioactive, and there should be no radiation dose to medical personnel from treating such patients. The patients will likely be scared and in pain; this should not be exacerbated by medical staff taking unnecessary and elaborate precautions.

Finally, remember that the immune system is unusually sensitive to the effects of radiation exposure. Patients who have received enough radiation to cause burns or radiation sickness may suffer from suppression of their immune systems and may require medical follow-up and antibiotic support. Since there is sometimes an asymptomatic period following the prodromal period, it may be prudent to keep patients under observation for several days after treatment.
Medical response to nuclear attack

Unlike the previous two scenarios, a nuclear attack will be truly devastating and many people will be killed and injured, many more will be traumatized, and a city's infrastructure may be severely damaged. Radioactive fallout can present in dangerous concentrations over many tens of square miles, people can suffer from thermal and radiation burns as well as inhalation of fallout.

All other factors being equal, a larger weapon will produce more damage than will a smaller one. A weapon set off at ground level will produce more fallout (be "dirtier") than a high-altitude burst because soil and building debris will become radioactive and will be swept into the fireball. Rain will wash fallout from the air, giving higher radiation doses to people near the explosion, but lower dose to people at a distance. Other factors will influence the severity of any attack as well, and are likely to vary considerably from site to site. However, even under ideal circumstances, any nuclear attack will have a horrific impact on the city attacked.

Even a single nuclear weapon will stress an area's emergency and medical response resources to the breaking point. If utilities are affected, medical personnel may be required to care for patients without reliable electrical power, heat, or water. However, unlike many Cold War scenarios, it is not likely that any terrorist group will possess enough nuclear weapons to attack a city with more than a single device. This means that large parts of a city will likely remain intact and able to provide assistance at the site of an attack.

In spite of these effects, medical personnel can play an important role in saving lives and treating the injured, as was shown in Hiroshima and Nagasaki after their respective nuclear attacks. Today, with the advantage of over a half century of research and planning, medical personnel can be even more effective at mitigating the health effects of a nuclear terrorist attack.

A nuclear attack will combine all of the elements noted above, and on a large scale. People closest to the weapon will be killed immediately and those somewhat further away will receive a fatal dose of radiation. However, depending on the yield of the device, local geography, weather, and other factors, people as close as several hundred meters may survive the explosion and its after-effects. Radioactive fallout will lead to many patients who are highly contaminated, some to the point of receiving a lethal radiation dose from their contamination if not promptly decontaminated. Complicating everything will be the presence of physical trauma – broken bones, thermal burns, crushing, lacerations, and so forth.

It is impossible to provide guidance in a book such as this one that will apply to any situation that may arise in a nuclear attack. Rather, it may be more appropriate to provide general guidance with the knowledge that medical personnel will have to react as appropriate, based on their own blend of experience, training, and knowledge. These general rules are:

1. Part of the triage process should include an assessment of radiation exposure received. For example, if a patient is vomiting or has diarrhea upon arrival, there is a good chance the patient was exposed to a lethal dose of radiation.
2. Accept that the emergency room will become contaminated and will require decontamination after the crisis has passed. Instead of trying to limit contamination to a few areas, it may make more sense to designate a few areas as "cold" areas and to use those areas for treating non-radiological patients. Alternately, it may be necessary to designate the entire emergency room as "hot" and to treat non-radiological patients in other parts of the hospital.
3. Contingency plans should include the loss of potable water, electricity, and/or heat. Medical staff should consider how they will continue to provide medical care to existing and incoming patients if utilities are lost.

Radioactive fallout can include "hot" particles. These particles can burn very localized parts of the skin, not affecting areas only a few cm away. The distribution of fallout can be very patchy, depending on peculiarities of terrain, weather, weapon characteristics, and other factors. People close to the site of the explosion may have lower radiation dose than those further away.

Patients from near the site of the explosion may look frightening and may have injuries that are simply impossible to imagine in advance. Medical personnel must expect to be confronted with situations for which their experience and training gives them no appropriate tools, technical or emotional. Even patients receiving a lethal radiation dose can be helped. Painkillers and antibiotics can help to make a patient comfortable and to help them survive until their family can be found.

Regardless of the severity of a nuclear attack and its consequences, medical personnel must do their best to respond to the best of their abilities. There will be many patients that cannot be saved, but they can be made more comfortable. There will be many more patients for whom medical care will mean the difference between life and death, and still others who may be able to assist with recovery once their injuries are treated.

Actions for medical personnel

Victims will necessarily be taken to medical facilities for further treatment. In past radiological accidents and exercises, medical personnel have sometimes proven reluctant to treat contaminated victims, often concerned that they, themselves may be adversely affected by exposure to radiation or radioactive contamination. These fears are virtually always groundless and, in the great majority of cases, medical care can be provided to victims without regard to health effects on persons providing medical care. In general, Universal Precautions will suffice to protect medical personnel against accidental ingestion or inhalation of radioactive materials, and the radiation dose rate from even highly-contaminated victims will pose no threat to those providing care. The most significant challenges are likely to be minimizing contamination throughout the medical facility and, in some cases, recognizing radiation injury. Luckily, many precautions taken to minimize the impact of radiological contaminants are very similar to those taken in the event of chemical or biological attack or, for that matter, for other potentially dangerous contaminants.

➢ *Contamination control*

There are two primary purposes for contamination control; to prevent personnel contamination and to prevent the contamination of facilities in which contaminated persons are present. Wearing proper protective garments is one way of reducing the risk of personnel contamination, and all persons working with or around contaminated victims should wear gloves, protective over-garments (e.g. "bunny suits, scrubs, etc.), and respiratory protection such as N-95 masks. Other measures may include frequent hand-washing, showering after each shift, changing outer garments after seeing each contaminated patient, and using disposable patient care items (blood pressure cuffs, thermometers, etc.).

Contamination controls also require limiting the ability of the patient to spread contamination through the medical center. Every effort should be made to decontaminate patients prior to their arrival at the hospital if at all possible, but this may not be advisable for badly injured patients.

If permitted by the patient's medical condition, some of the following actions can be taken to minimize the spread of contamination from such patients:

1. Wrap the patient in a sheet, blanket, or other material at the scene or outside the hospital doors
2. Dress the patient in contamination-control clothing such as a Tyvek coverall at the scene or at the hospital door
3. Establish a contamination control "corridor" from the ambulance drop-off area to patient treatment rooms. Such a corridor may be a path designated only for contaminated patients, or personnel can lay down plastic, plastic-backed paper or similar materials to help contain contamination. The corridor should be kept well-separated from "cold" areas to the maximum extent possible.
4. Mildly injured patients can be sponged, showered, or washed prior to entering the hospital.
5. Maintain dedicated "hot" rooms for diagnosing and treating contaminated patients, and keep these rooms well-separated from "cold" rooms

To reduce the spread of contamination from patient rooms, medical personnel should take some or all of these measures:

1. Remove gloves, shoe covers, and outer garments prior to leaving the room. These should be discarded into designated containers in or very near the contamination zone.
2. Wash hands prior to leaving the patient's room or prior to touching anything not in a contaminated area.
3. Use sticky step-off pads at the door to trap contamination carried on the feet.
4. Maintain dedicated waste containers for all waste from contaminated patient rooms

Medical personnel must also be prepared to deal with large numbers of patients who arrive on their own. Many of these patients may well fall into the "worried well" category, but will nevertheless require attention of some sort. Medical facilities may with to consider developing information handouts to give to such patients to help explain why radiation injury is unlikely and why they will neither be admitted to the hospital nor provided with medical attention.

Medical personnel may rule out radiation injury if they are aware of radiation levels measured at the scene; if the highest radiation field is only a few rem per hour, for example, radiation sickness is implausible. However, scattered radioactive sources can have very high radiation levels and, if held in the hand or in direct contact with the skin, can produce radiation burns.

It may be necessary to obtain samples from some patients, usually to check for non-radiological medical parameters. However, urine and fecal samples may be taken to check for radionuclide uptake, blood samples may be used for biodosimetry, and nasal or oral swabs may be obtained to indicate ingestion or inhalation of radioactive materials. In obtaining non-invasive samples, care must be taken to avoid contaminating the sample. Sample containers should be clean and, if possible, contact with contaminated parts of the body should be avoided. For example, the patient may need to wear gloves to avoid contaminating a urine sample container. In obtaining

invasive samples (e.g. blood samples), the sample location should be swabbed to avoid introducing radioactivity into the body.

Hospitals with radiation safety departments will wish to include radiation safety personnel in their planning and response efforts. Radiation safety personnel can assist with contamination controls, handling of contaminated or radioactive samples, radiological surveys, and other routine tasks for which medical personnel may be unprepared. Medical institutions lacking a dedicated radiation safety (health physics) organization may wish to take advantage of the experience of medical physics, nuclear medicine, and/or radiation oncology staff, all of whom are likely to have experience in handling radioactive materials and using radiation survey instrumentation.

Recognizing radiation injury

Many medical practioners have had difficulties in recognizing radiation injury because radiation injury is not normally expected. Radiation injury patients may be seen as a result of excessive fluoroscopy or radiation oncology, and there are occasional accidents involving radioactive sources that can result in severe burns or radiation sickness. However, such accidents are rare, happening perhaps once annually or less frequently. In the event of radiological terrorism, however, radiation injury is not unexpected and is more likely to be recognized.

Radiation burns can resemble thermal burns, but radiation alone will not cause thermal effects such as charring. In the short term, radiation burns are associated with redness, swelling, and possibly pain. This may be followed by ulceration, bleeding, peeling skin, and blistering. Although thermal effects are not associated with radiation burns, a chemical explosion and subsequent fires do, and a terrorist attack may lead to both radiation and thermal burns. In other words, the presence of thermal effects following a terrorist attack need not rule out the presence of radiation burns. Medical personnel should look for secondary indicators of radiation exposure, such as white blood cell depression, nausea and vomiting, or elevated numbers of chromosomal abnormalities. These symptoms may not manifest themselves for several hours or days after exposure and, for radiation burns of limited extent, may not be in evidence at all. For this reason, if radiation burns are suspected, it may be necessary to treat the injury as a radiation injury until a physician experienced in radiation injury can provide a definitive diagnosis.

In the event of an irradiator attack designed to inflict radiation sickness, physicians may expect to see patients exhibiting symptoms of radiation sickness. At relatively low levels of exposure (up to about 100 rem), these symptoms may include nausea, vomiting, and diarrhea, and these symptoms may not appear for hours or days after the initial exposure. Further symptoms can include loss of consciousness, loss of appetite, and cramps. In general, any patient whose unconsciousness is caused by exposure to radiation is not expected to survive, although this prognosis should be made by someone experienced in radiation injury. It would be unfortunate for an inexperienced physician to mistakenly determine a patient has received a lethal radiation dose when, in fact, they received a simple head injury. Unfortunately, radiation exposure does not necessarily produce a unique set of symptoms, so proper diagnosis may depend on observing other indicators that may not occur for some time after the exposure.

Because of the difficulty of recognizing some radiation injury, hospitals may consider having some medical physicians and staff attend training in this area such as that offered by the Oak Ridge Institute of Science and Education (the URL for which is http://www.orau.gov/orise.htm).

Chapter 6: Managing the Aftermath of a Radiological Attack

If a radiological attack is successfully carried out society will be faced with medical, psychological, social, political, economic, organizational, and other challenges. Many of these challenges have been experienced in radiological and other settings in the past, and radiation safety professionals know what to expect to a large extent, although these issues have not been seen on a scale similar to what might be seen in the event of a successful radiological attack.

Although there have been no known successful radiological attacks, there have been several instances of widespread contamination. Of these, perhaps the most instructive is that in Goiania, Brazil, described in detail by the National Council on Radiation Protection and Measurementsn (NCRP). In this incident, an "orphaned" Cs-137 radiation therapy source (1375 Ci, 50.9 TBq) was found by unsuspecting residents, who managed to open the source. Fascinated by the blue powder they found, residents played with it and spread it on their bodies, unaware of its radioactivity. By the time the nature of the source was known, about 250 people had been exposed to elevated radiation levels, 103 had evidence of ingestion, and five died of radiation sickness.

During the course of the incident and recovery, more than 3000 cubic meters of contaminated materials were removed for disposal and nearly 34,000 persons were surveyed for contamination at the city's soccer stadium (of whom only a few hundred were actually contaminated). The recovery process was time-consuming and expensive. However, the social impact was far greater and, even a decade later, Goiania residents were stigmatized by their association with the region. This stigmatization included an economic impact because sales of agricultural products from Goiania experienced a significant decline. Similarly, the NCRP suggests that a successful RDD attack may also produce significant social and economic impacts on the city attacked.

In the immediate aftermath of a radiological attack, it will be necessary to manage the scene and the city so that the scene is stabilized, victims are cared for, and essential city services maintained. At the same time, some foresight may help with later recovery efforts.

Immediate actions at the scene – general public

A great deal of thought has been given to actions that the general public should take. In general, it is thought that anyone who cannot directly see or hear an explosion need not worry about the effects of the explosion on them. Similarly, those who are upwind of an attack are very unlikely to be contaminated. Accordingly, only those in the immediate vicinity of an explosion or those who are downwind of an explosion have the potential to be contaminated. Such persons should remember that contamination is contained in the dust and debris from the explosion and can only travel as rapidly as the dust is carried on the wind – a small delay in taking actions is not necessarily damaging, but all delays should be minimized as much as possible. Actions that the general public should take are:

1. Shelter – go indoors and shut open doors and windows.

2. Do not drive away from the scene – driving is more dangerous than small radiation doses and, by driving, you may make it more difficult for emergency response vehicles to travel to and from the scene of the attack
3. If possible, change clothes and take a shower
4. Turn on your radio or television to listen for news updates
5. Stay put inside for at least two hours or until you hear that your location is not located within the plume
6. If you are located within the plume, remain indoors with doors and windows shut until authorized to leave by emergency response personnel to minimize inhalation.

- ***On the scene***

The site of a radiological attack, as with any terrorist attack, can be expected to be chaotic at first with the chaos gradually lessening as the scene is controlled. The extent of the chaos will depend on the location, nature, and extent of the attack. A "dirty bomb" attack will leave in its wake all the chaos that has accompanied other terrorist bombings. The detection of radioactivity in the debris, or the announcement of a radiological device by the terrorists can be expected to increase the level of confusion at first, and response efforts may slow or stop until radiological survey and dosimetry equipment can be brought to the scene. The presence of radiological survey instrumentation on emergency response vehicles will help to reduce this delay, and it may be advisable for cities that are at higher risk of attack to ensure that survey instruments are included in the inventory of emergency response vehicles responding to explosions or other possible terrorist attacks.

The Incident Command Structure (ICS) was developed to provide a flexible, consistent, and reasonable method of responding to emergencies. The ICS can accommodate terrorist attacks, including those involving the use of radiological materials, but only if the city's emergency responders are trained in radiological emergency response or if they have arranged the participation of radiation safety (health physics) professionals. Health physicists can help assess the radiological portions of the situation to determine the significance of radiation dose and contamination readings, calculate stay times for responders, recommend radiological protective actions, and so forth.

Those in charge of the incident response should make every effort to locate themselves sufficiently far upwind of the scene of the attack to minimize the possibility that they will be contaminated, to avoid the necessity for decontamination when they or others must leave the scene. In general, large particles will settle close to the scene and smaller particles will drift downwind, so it should be possible to locate the command post and incident commander within 100 meters of the site of the explosion in the upwind direction. Those personnel who must be located within potentially contaminated areas (i.e. closer than this distance) must be garbed in anti-contamination clothing, including shoe covers, protective gloves, and an outer garment that can be removed when leaving the contaminated area. If there is visible dust in the air, personnel should also wear breathing protection to guard against inhaling radioactive particles.

It may also be necessary to identify potentially contaminated persons, and such persons will not be confined to the immediate site of the attack. Although most of the debris will settle in the vicinity of the attack, fine particles may travel downwind for a considerable distance – up to a

few kilometers – and exposed persons may require decontamination. However, as noted below, contamination can be easily detectable without posing any risk to contaminated persons. It may be necessary to release moderately contaminated persons without decontamination so that emergency response resources can be devoted to those whose lives or health are at risk.

- ***Victims***

Most bombs injure or kill people and "dirty" bombs are presumably no exception. The site of a radiological bomb can be expected to include fires, debris, damaged buildings, and injured people. Saving lives and reducing suffering will require prompt rescue, emergency medical care, and transportation to a hospital or trauma center.

Emergency responders need to understand that even high levels of contamination will pose no health risks to emergency responders who take universal precautions. Radiation levels from contaminated victims are too low to cause radiation sickness, so taking precautions to avoid radioactive materials ingestion or inhalation should suffice to limit emergency responder radiation dose to safe levels. Emergency response personnel should neither delay, deny, nor limit emergency care to victims on account of radiation or contamination on the patient.

When rescuing victims, emergency responders must follow routine precautions, including waiting to move a victim until the victim can be stabilized. However, if the victim is in a hazardous position due to fire, collapsing structures, or very high radiation levels, external risks may require moving the victim to a safe area prior to rendering assistance. This must be a judgment call made at the scene by the emergency responders.

Although a radiation level of 100 rem/hr (1 Sv/hr) seems (and is) quite high, 4 hours of exposure is necessary to be fatal to half of those exposed in the absence of medical care. This means that, even in a 100 rem/hr radiation field, it is possible to spend a half hour or more to stabilize a badly injured patient prior to transport. In fact, dose to the emergency responder may limit rescue efforts because, according to NCRP Report #138, responder dose limits of about 50 rem should be observed when possible.

In the case of exceptionally high levels of alpha contamination (in excess of a few tens of thousands of counts per minute, depending on the isotope present), inhalation of resuspended radionuclides may be a concern. In such cases, respiratory protection will help reduce uptake to the emergency responder, but such protection may not be feasible for victims with facial or chest injuries. In such cases, prudence may dictate rapid removal of the victim to a less-contaminated area, where the victim can be stabilized further.

Contaminated victims can spread contamination via contaminated clothing. When possible, emergency responders may consider removing the victims' clothing prior to transportation, wrapping victims in blankets or sheets to contain contamination, or similar measures to limit the spread of contamination. Such measures, however, should not be taken unless permitted by the victim's medical condition.

➢ *Emergency responders*

Shortly after the announcement of any emergency, emergency response personnel are dispatched to the scene of the event. Depending on the sort of event, these may include fire, police, and/or medical personnel, each with defined roles. Incident commanders will also arrive, and in many cases, elected or appointed public officials will also arrive at the scene. The goal of emergency response is to take immediate actions to stabilize the scene and rescue injured personnel, although at times, rivalries between separate emergency response organizations may complicate the desired smooth flow of activity.

It is not implausible that emergency response efforts may commence prior to recognizing the presence of radioactive materials at the scene. This means that some degree of external and internal radiation exposure may occur before any protective actions are taken. Some cities have given radiation "pagers" to their emergency responders to help avoid this possibility, but many have not. In addition, among those cities that have distributed some sort of radiation detector, not all have given consistent or reasonable advice to their emergency responders regarding the interpretation of readings. Obviously, it is advantageous for agencies to have similar action levels, and for these action levels to make sense from standpoints of both radiation safety and emergency response. For example, strict emergency response criteria may dictate responding to an incident without regard to radiation dose rates, but such criteria ignore emergency responder safety. The alternate extreme to this would be criteria in which any detectable radiation dose would lead to abandoning emergency response efforts; such criteria could, however, lead to ignoring fires, structural stability, and victims' health. Optimum dose limits, therefore, must account for responder safety, treating victims, and addressing fire and other hazards.

As discussed in previous sections, a radiation dose as high as 100 rem (1 Sv) has little short-term health impact; such a dose will induce radiation sickness in a fraction of exposed persons and will increase long-term cancer rates by up to 5% (although these factors are subject to some debate among scientists). Accordingly, emergency responders can be expected to function unimpaired for some time even after receiving doses of this magnitude. Because of this, and to give room for a margin of error, the NCRP has recommended emergency responder be allowed to receive up to 50 rem each in order to save lives, rescue victims, or to take those actions necessary to stabilize a situation (e.g. extinguish fires, stabilize structure). This means that, in radiation fields of up to several rem/hr, emergency responders may attend to emergency actions almost without regard to external radiation fields, although precautions should be taken to minimize the possibility of ingestion, inhalation, and skin contamination. For this reason, it may be reasonable to designate radiation fields as "low" if the risk of reaching 50 rem is virtually nonexistent, "medium" if a worker may approach a cumulative dose of 50 rem in a single working day, and "high" if the radiation dose rate is sufficiently high as to dictate the length of time an emergency responder can remain in the area. Please note that, even in a "high" radiation field, non-radiological factors (work load, air supply, heat stress, etc.) may be more important factors in determining stay times than would be the radiation dose. The following table summarizes this information for ER (Emergency Response) low, medium, and high radiation dose areas in emergency situations as defined above (please note that these are not intended to conflict with regulatory definitions of radiation areas and high radiation areas).

Designation	Dose rate range (based on 10-hour shift)	Working time (to maintain dose less than 50 rem)
Low	1 rem/hr	≥ 50 hours
Medium	1 – 5 rem/hr	10 -50 hours
High	> 5 rem/hr	≤ 10 hours

When possible, entries into radiological areas should be made with the following equipment and personnel resources:

1. Radiation dose-rate instrument (to identify "hot spots" and map radiation fields)
2. Radiation count-rate instrument sensitive to alpha, beta, and gamma radiation (for contamination levels)
3. Personal dosimeters for at least one person per team (this can be used as a proxy for dose to all team members)
4. Respiratory protection (to reduce dose from inhaled radionuclides)
5. Protective clothing (to reduce contamination of bare skin)
6. Radiation safety professional (to provide advice in radiological matters)
7. Contamination control equipment (e.g. sheets, Tyvek suits) for lightly injured victims (to minimize contamination of ambulances, exit areas, and hospitals)
8. Notepad (to record relevant radiological and medical information, if circumstances permit)
9. Reliable communications with incident commander

It may be necessary to enter a potential radiological area without radiation dosimetry or without radiation survey instruments in order to provide urgent medical care or to stabilize a dangerous situation. For example, badly injured victims may not have the luxury of waiting until radiation survey meters arrive at a scene, and it may be necessary to immediately bring a fire under control or to stabilize a structure in order to avert further disaster. In such cases, the incident commander may decide it is necessary for emergency responders to enter an area and work with all deliberate speed to take what actions are necessary to prevent loss of life or widespread damage. Such decisions are similar to sending personnel into a burning building, into collapsing structures, or into heavy seas to effect a rescue – in such cases, on-scene personnel must weigh the certain risks to victims or to the city against the possible risks to emergency response personnel, and it is not appropriate for such decisions to be made in advance in a paper such as this. If it is necessary to have personnel enter a radiological area without radiation detectors or personal dosimeters, every effort should be made to minimize the amount of time any single person is in the area and to enter the area(s) with radiation dose-rate instruments at the earliest opportunity so that the dose received by both victims and emergency responders can be calculated. For example, if a particular worker was known to have spent 30 minutes in an area and subsequent radiation surveys in that area indicates dose rates of 10 rem/hr, the worker probably received a radiation dose of 5 rem while in that area.

Emergency responders may have to leave and re-enter work areas frequently because of escorting victims from the area, to change air bottles, for heat stress and fatigue considerations, for personal safety, and so forth. Since it is unwise for persons to eat or drink in contaminated areas, it may be necessary to establish "clean" areas for these purposes. In the first hours of an

emergency, the press of events may preclude setting up such a clean area, and shortage of personnel may preclude the time needed for persons to enter and leave such areas; in such cases, it may be acceptable to have an area near the boundary that is set up with hands-free eating, drinking, and other facilities. For example, squeeze bottles with straws or water fountains may make it possible to drink without risk of internal contamination, uncontaminated persons can change air bottles or feed emergency responders, and so forth.

Prior to leaving the contamination zone, workers should remove their outer clothing (or turn-out gear or anti-contamination clothing) and place it in special containers for later laundering or disposal. They should then be surveyed from head to foot for radioactive contamination, paying special attention to the face (including mouth and nose), hands, and feet. Any areas found to be contaminated should be decontaminated with mild soap and cool to warm water. More stringent decontamination measures may be required, but should be taken only as recommended by radiation safety emergency response professionals. If there are large amounts of airborne contamination from the device or from resuspension, workers should consider showering and changing into new clothing and leaving the scene.

- ***Unaffected bystanders***

A radiological attack may result in the contamination of large areas, even though most of the people in these areas may be unaffected. For example, persons working inside of a building may be uncontaminated, but the streets outside the building may be heavily contaminated by an RDD. The incident commander may wish those persons to remain in their building until an exit corridor can be cleared or, at least, a plastic "runway" put down to establish an uncontaminated exit route. Depending on the amount of time such actions take, people may be trapped for hours or days. In such cases, people would have access to fresh water, toilet facilities, and, perhaps, limited amounts of food, but any large group of people in such a situation may be subject to high levels of stress or to unrelated medical emergencies (e.g. heart attacks, panic attacks, etc.). Accordingly, emergency response plans should include the need to radiologically characterize such buildings, restrict the exit of persons from these buildings through or into the controlled area, and to render necessary assistance to people in such buildings. Addressing such needs would be much easier with a clear organizational structure in each building, but in reality, such a command structure would be hard to enforce and maintain in a civilian facility with high levels of turnover.

It is also very likely that large numbers of uninjured people outside may find themselves in a controlled area in the wake of a "dirty bomb" attack. Such people may or may not be contaminated, and even those who are contaminated may vary in the levels of contamination they exhibit. Some suggested field screening methods are outlined in the following section, but even rapid screening of tens or hundreds of thousands of people can be a lengthy process. This means that emergency responders may need to provide for water, toilet facilities, survey locations, new footwear, clothing changes, first aid, and other needs for these people for several hours of time. In the event an attack takes place in bad weather, these persons may also require shelter, warm (or waterproof) clothing, heaters, and similar items. In short, emergency responders must be prepared for the possibility of providing basic needs for large numbers of people who are not injured, possibly only mildly contaminated, but nevertheless stuck outside for prolonged periods of time. Since people in such situations are likely to be worried and

frightened and may become restive, enforcing boundaries may be a difficult and staff-intensive operation. Input from crowd-control experts may be helpful in formulating plans for such eventualities.

Depending on the numbers of people involved, it may or may not be possible to survey all people in the affected area, and it may not even be possible to attend to all uninjured persons who are contaminated. If the number of people affected is high, the most prudent measure may be to establish local screening criteria and simply release all persons meeting these criteria, providing them with verbal or written instructions as they leave. Such instructions would include actions to take (i.e. change clothes, shower, launder contaminated clothing 2-3 times) and could be repeated on radio and television stations as a reminder. This action would inevitably lead to spreading contamination beyond the affected area. This could be mitigated to some extent by collecting shoes and/or issuing shoe covers to those leaving the area, but contaminated clothing would still spread contamination to cars, public transportation, and homes, albeit at low levels. If such a decision is anticipated, public health and other regulatory officials may wish to determine in advance what criteria to use for such releases and how to attend to subsequent contamination. Given that the health effects of low-level contamination is very small, it may be that the simplest and lowest-cost solution would be to relax the regulations governing radioactive contamination somewhat so that the health risk remains very low, but that respects the desire to maintain contamination levels at a level acceptable to the general public. This is discussed in further detail in a following section of this chapter.

People may exhibit severe symptoms stemming from anxiety and not from any injuries. These "worried well" can pose problems at the scene as well as at local medical facilities. As noted above, over 34,000 persons in Goiania were present for contamination surveys, in spite of the fact that only a few hundred people were found to be contaminated. By extension, we can anticipate that many people may refuse to leave a controlled area without first receiving a radiological survey, that some may insist on a more thorough survey than is warranted, or that even those outside of contaminated areas may appear at medical or emergency response locations demanding to be surveyed. Such persons may be difficult to placate, and they may interfere, however unintentionally, with effective response efforts. In subsequent days, others may claim to be suffering the effects of radiation sickness because of headaches, nausea, or other symptoms of anxiety; these people may place continuing demands on medical and emergency response resources and planners should consider how best to deal with them in such a way as to be sensitive to their needs, but without letting excessive attention detract from the needs of responding to the emergency and to legitimate victims.

In spite of the worried well, most people are fairly reasonable and can be expected to accept instructions and recommendations from authority figures. Others, indeed, may desire their expedient release regardless of contamination levels. The latter group may be best handled by effective boundary controls. The former group may be best served by distributing informative literature to those released from the controlled area and by making this information available on-line, in the printed media, and via radio and television.

➢ *Boundary controls*

Boundaries are used to distinguish areas needing attention from those that do not. In the case of a radiological attack, boundaries may be used to ensure potentially contaminated persons are properly surveyed, to ensure a crime scene is not disturbed, to keep people from potentially hazardous areas, to distinguish areas requiring regulatory controls, and so forth. Or, in other words, boundaries exist to either keep people in an area, or to keep people out of an area. When established, a boundary must be controlled or it loses meaning and effectiveness. Longer boundaries are not only difficult to control, but they also contain larger numbers of people. For this reason, boundaries must be sufficiently large to encompass all areas that must be controlled, but small enough to be manageable. Since it is easier to collapse a boundary than to enlarge one, it may be prudent to establish initial boundaries that are large and to reduce their size based on survey information.

A boundary must consist of a barrier that is obvious and that requires a conscious effort to cross. Yellow plastic tape is often used, although radiological boundary tape may include the color magenta as well. If a potentially contaminated area is very large, the boundaries may be several kilometers in length, and a significant law enforcement effort may be required simply to enforce boundary controls.

Leaving a controlled area must be a conscious act on the part of the persons crossing and controlling the boundary. If a person is within a potential contamination zone, they must meet criteria for leaving the controlled area. These criteria may include personal contamination levels, area contamination levels, or expedience. For example, a person may be required to exhibit low contamination levels, an area may be found to have acceptable contamination levels, or the incident commander (in conjunction with public officials) may decide that the potential further spread of contamination is a lower risk than is keeping tens or hundreds of thousands of people waiting in cold or rainy weather until they can be surveyed properly.

Setting radiological boundaries may be based on dose rate or contamination level criteria. Some of these criteria are listed below:

Boundary criteria	**Boundary level**	**Regulatory requirement**
Radiation dose rate	2 mr/hr	Limit for radiation dose in an uncontrolled area
	5 mr/hr	Must be posted as a radiation area
	100 mr/hr	Must be posted as a high radiation area
β, γ contamination	1000 dpm/100 cm^2	Limit for removable contamination
	5000 dpm/100 cm^2	Limit for fixed plus removable contamination
α contamination	20 dpm/100 cm^2	Limit for removable contamination
	200 dpm/100 cm^2	Limit for fixed plus removable contamination

It must be noted that these criteria are determined by regulations and not by the expected health effects from exposure to these isotopes. This brings us back to the comment above that areas requiring decontamination to comply with regulatory requirements may pose little or no health threat, raising the possibility that, in an emergency situation, strict compliance with such regulations may be counter-productive if this compliance consumes time and resources to the point that emergency response is compromised. In such cases, it may be necessary to allow

some degree of regulatory non-compliance so that emergency response resources are dedicated to helping those whose health is at risk. It may be best to simply send others home with instructions to discard contaminated clothing and shower thoroughly, requiring at most that they exchange their contaminated shoes for non-contaminated disposable footwear.

Finally, there must ingress/egress points in the boundaries that are established. People entering a controlled area must be authorized to do so, and it may be best to establish rules for entry (e.g. emergency responders in turnout gear or uniforms may enter at any point while other authorized persons may only enter at specified locations or in the company of emergency responders). All persons entering the controlled area should be logged in and, if radiation levels are sufficiently high, should be assigned stay times. Those exiting controlled areas should do so only at designated points so that they can survey themselves, remove contaminated clothing, log out of the area, and receive any necessary further instructions. Egress areas should include a survey area, a step-off pad (if possible), bins for contaminated clothing, and replacement clothing if possible. Decontamination equipment should also be present so that contaminated personnel can be released to unrestricted areas when they exit the controlled area. There may need to be multiple exit points to accommodate a large number of people working (or milling about) in a large area – the number of exit points will probably depend on available staff and resources.

- ***Field screening***

If large numbers of people are to be released from potentially contaminated areas, there must be some relatively rapid, effective, and (hopefully) accurate means to differentiate between those persons requiring further attention (e.g. medical care, bioassay, decontamination) from those who can be sent home without additional care. Field screening methods may be based on monitoring individual persons, monitoring groups of people, monitoring areas, making presumptive decisions, or a combination approach. It must be noted that the following are suggestions only and that they have not been worked out in detail; details such as actual readings that would indicate the need (or lack thereof) of further attention.

Individual monitoring may be used to quickly screen each person in a controlled area. In the case of high-energy beta and gamma-emitting isotopes, one can expect a high detection efficiency, and a short count on representative areas may be sufficient to indicate the presence of high levels of contamination. For example, a 1"x1" sodium iodide detector may have 10% detection efficiency for Cs-137 and a background count rate of about one or two thousand counts per minute. If we assume a 1 minute background with a count rate of 1000 cpm, a detector efficiency of 10%, and a "sample" counting time of 10 seconds, counting statistics tell us that the lowest level of contamination that can be reliably identified (the minimum detectable activity, or MDA) is about 500 dpm/cm^2, which is significantly in excess of the 10 dpm/cm^2 permitted by regulations. A one minute counting time per person gives an MDA of about 300 dpm/cm^2, an advantage over the shorter counting time, but not sufficient to warrant the added counting time. Consider – performing a 10 second count on each of 10,000 people will take 100,000 seconds or nearly 28 hours, not including the time needed to give instructions to the person surveyed and begin the next survey (which would, conservatively, double the total counting time). Establishing multiple counting stations will, of course, reduce this amount of time, but this requires personnel to establish and staff each location. In addition, an RDD attack in a densely populated location such as New York City will almost certainly lead to many tens of thousands,

perhaps hundreds of thousands of potentially contaminated persons. For very large numbers of persons, even with a relatively high threshold for release, surveying each person in a controlled area is not a good way to clear large numbers of people in an efficient manner. If people are surveyed, it would seem reasonable to survey the top of the head, the shoulders, and/or the bottoms of the feet as areas most likely to be contaminated by materials settling from the air onto horizontal surfaces (including the ground).

However, we must bear in mind that it is may not be necessary to demonstrate a particular MDA in order to clear a person from a contamination area. The smallest gradation on a survey meter is usually on the order of 20 counts on the lowest scale (0-500) or 200 counts on the next-lowest scale. Accordingly, a surveyor may need only 10 seconds to show that indistinguishable from background

An alternative method may be to survey a subset of people in a given area. For example, surveying 1% of people in remote locations may suffice to demonstrate that a population is likely either uncontaminated or contaminated to sufficiently low levels that they can be released from the area. In such a scenario, 1000 people can be surveyed for 10 seconds each, taking a total of 10,000 seconds, or nearly 6 hours for surveys plus moving people through the survey point. Thus, a 1% sampling in areas not expected to show high levels of contamination may be an acceptable alternative to 100% sampling to demonstrate that large numbers of people either can be released from the area or must be kept for further surveys or decontamination. Of course, if a sampling is performed, care should be taken to select a representative sampling of the crowd. In addition, as areas surveyed approach the site of the attack (or as contamination levels increase) it may be necessary to increase the fraction of persons surveyed.

Instead of surveying individuals, it may be possible to perform area surveys and, if an area is found to be only moderately contaminated, to release all persons in that area. Such surveys, however, require some degree of confidence that persons have not moved from heavily contaminated areas to regions of lesser contamination. For that reason, it may be advisable to survey some individuals, if only to confirm that such movement has not taken place. Using the same assumptions in the previous example, a 10 minute background count and 10 minute counts at each sample location will give an MDA of about 95 dpm/cm^2. However, as noted above, a shorter count may suffice to show that an area either is or is not heavily contaminated. If the area is not heavily contaminated, as indicated by a count rate very close to background levels, it may be decided that persons in that area may be released without further survey, or after surveying a small sampling of those persons. Of course, contamination levels should be checked at multiple locations to confirm that the entire area contains acceptable levels of contamination.

It may also be possible to make presumptive decisions based on meteorology, plume modeling, or other factors. For example, persons more than a few tens of meters upwind of the site of the release may be assumed to be uncontaminated, and it may be decided that persons more than 100 meters from the plume centerline, or persons more than 1 km downwind of the plume may be similarly assumed to be either uncontaminated or contaminated to very low levels.

In the city

In addition to managing the scene of a terrorist attack, it will be necessary to ensure that the city as a whole remains able to provide necessary services to its residents. For example, if every law enforcement official is sent to help establish and enforce radiological boundaries, they are not available to provide their normal services in those parts of the city that are not directly affected by the attack. Similarly, sending every available ambulance to the scene of a radiological attack may result in the contamination of every ambulance, rendering them unsuitable for use for non-radiological patients until decontaminated.

➢ *Managing contamination levels*

One consideration is that of managing contamination levels downwind of the attack and, if lightly contaminated persons are permitted to leave the scene, managing contamination levels in residential neighborhoods and private homes. As discussed above, it may be impossible to survey every person in the controlled area, and it may be decided that even measurably contaminated people can be sent home without decontamination so that attention can be given to the injured and the most heavily contaminated.

There is some precedent for contamination distributed on municipal streets: the city of Denver is currently involved in remediating streets contaminated with radium from past industrial practices. For example, many streets and other areas are permitted to retain elevated contamination levels, provided the anticipated dose to those living and working in these areas does not exceed 25 mrem/yr. Similar risk-based criteria may be considered as alternatives to extensive decontamination of the city or persons in a contamination zone. Potential impacts of such decisions are:

Property values may drop if homes or neighborhoods are known to be even lightly contaminated
Run-off from contaminated streets may contaminate storm drains, ponds, or other areas in which run-off from large areas can collect and settle
Municipal water treatment plants may become contaminated if large numbers of people wash themselves or their contaminated clothing

City officials and the incident commander may have no choice except to release people from the scene, even if these people are somewhat contaminated. These people will inevitably spread contamination to their homes, apartment (or condominium) buildings, and neighborhoods and this contamination may be in excess of regulatory limits. Although even relatively high levels of contamination (compared to regulatory limits) may pose little to no risk, it may nevertheless cause future problems because of the general public's fear of radiation and radioactivity. These fears and the concerns noted above may make it necessary for government officials to take some or all of the following actions:

1. It may be necessary to institute radiological controls and undertake remedial actions at municipal waste water treatment facilities
2. If water treatment sludge is incinerated and landfilled, this ash may be radiologically "hot", requiring special care or special dispensation for disposal

3. Local, state, or federal governments may consider ways of maintaining property values in contaminated neighborhoods as an alternative to remediation.
4. Environmental radiological surveys should be performed in areas downhill and downstream of the attack site and other contaminated areas. Cities may wish to consider commissioning aerial radiation mapping surveys following completion of incident response activities

Managing medical transportation and care

Another consideration was hinted at above – maintaining the city's ability to care for all victims and patients, not just those involved in the terrorist attack. Suppose, for example, that all available ambulances arrive at the scene to begin ferrying victims to the most convenient hospitals. As patients are taken to the nearest hospitals, they become overwhelmed and new ambulances begin taking patients to more remote hospitals. The most badly injured are also most likely to have been close to the scene of the attack and, hence, to be the most heavily contaminated. This means, inevitably, that the ambulances in which they are transported and the hospitals to which they are taken are likely to become contaminated as the immediate actions run their course. This is not to imply sloppiness or lack of attention to detail on the part of emergency response or medical personnel; it is simply a very likely outcome because caring for patients' medical concerns will (and should) take priority over contamination controls. In addition, as ambulances and other emergency response vehicles drive over contaminated streets, onto contaminated sites, and so forth, they will at the least get contaminated tires, and other parts of the vehicles are likely to become contaminated as well. In the aftermath of the immediate actions, it is entirely possible that the city will find itself with very few uncontaminated ambulances and even fewer uncontaminated emergency rooms; city officials may be forced to choose between knowingly using contaminated facilities and equipment versus diverting the few "clean" vehicles to more remote medical facilities until decontamination efforts are completed. This added response and transportation time may, in turn, result in additional medical complications, perhaps even lost lives, until access can be restored to all medical facilities. Some of the following actions may help address these concerns:

1. Equip all emergency rooms with decontamination facilities, anti-contamination clothing, and plastic contamination control corridors to limit the spread of contamination into the hospital
2. Require some hospitals develop alternate emergency rooms with alternate entrances so that a single hospital (or trauma center) can handle both radiological and non-radiological patients simultaneously in separate facilities
3. Designate some hospitals as non-radiological medical centers so that all non-radiological patients are taken to these centers and all patients from the site of the attack are funneled to medical centers designated for radiological patients only.
4. Equip some emergency response vehicles with contamination control equipment to help minimize vehicle contamination
5. Develop rapid-use contamination control patient coverings (e.g. sheets or blankets) and train emergency response medical personnel in their use to help minimize the spread of contamination from victims
6. Take actions to limit the liability of medical, ambulance, and emergency medical personnel and institutions during terrorist attacks or radiological incidents

Our current medical care paradigm is patient-centered; medical personnel make every effort to treat every patient to the best of their ability. In the event of a mass casualty situation, it may be necessary to change this paradigm to a community-centered one in which medical personnel ration care to individual patients so that the community as a whole is best served. This may involve limiting medical care to some patients, providing only palliative care to patients not likely to survive, limiting access to some medical centers for some categories of patients, and so forth. In some cases, the medicine practices may resemble battlefield medicine more than current standards of practice, and this may be disconcerting to medical practitioners and patients alike. This analogy is probably more correct than we would like to admit, but we must consider any terrorist attack to be equivalent to a military attack, and the military paradigm is more likely to be appropriate for such a situation than is our current standard of treatment in the absence of mass casualties.

Comparison with other forms of disaster

Every sort of disaster, natural or man-made, is unique and carries with it unique challenges. A terrorist attack using radiological weapons has its own unique characteristics, many of which have been described in the preceding parts of this primer, and whatever response is crafted for a terrorist attack will necessarily need to address these characteristics. For example, our response to radiological terrorism will have to consider the potential for the inhalation of alpha contamination, the spread of radioactive contamination to the environment, the public fear that accompanies most mention of radiation, the lack of information on the part of most physicians, and more.

Nevertheless, we can expect many commonalities between a radiological attack, other forms of terrorist attack, natural disasters, and other large-scale urban disasters. For example, any event that causes casualties will require medical transportation and medical attention for victims. Any event that affects electrical power generation will impact on medical care, food preservation and availability, security, sanitation, and the availability of water. The following tables summarize some of these commonalities for a wide range of disasters, both natural and man-made.

	Item	Type of loss	Mitigating the effects of a loss	Status after Katrina?	Protection from terror attack?
Transportation	Bridges and tunnels	Destruction via attack	Repair, rebuild, re-route traffic, use ferries (if possible)	Flooded or destroyed	Strengthening offers some protection
		Chem., rad, bio contamination	Re-route traffic, decontaminate, resurface	Contam. sediments	None
		Blocked by those fleeing event	Crowd and traffic control, use alternate routing for emergency vehicles, use helicopters if possible	N/A	Traffic control may help, but not likely
	Roads, rail lines	Destruction via attack	Repair, rebuild, re-route traffic	Flooded or destroyed	Dikes, levees – are susceptible to failure or sabatoge
		Chem., rad, bio contamination	Re-route traffic, decontaminate, resurface	Contam. Sediments	None
		Blocked by those fleeing attack	Crowd and traffic control, use alternate routing for emergency vehicles, use helicopters if possible	Traffic jams prior to Hurricane Rita	Traffic control may help, but not likely
	Air	Destruction via attack	Repair, re-route to alternate airport until repaired	Temp. denial of use	None
		Chem., rad, bio contamination	Decontaminate, use alternate airports until decontamination is complete	N/A	None
Power generation	Electrical generating stations	Power transmission component destruction (e.g. power lines, transformers)	Mitigation and recovery will likely use existing technology, however work may be made more difficult by presence of CBRN agents	Widespread power outages	Offers some protection
		Disabling generators	Mitigation efforts will likely use existing technology – e.g. try to design "tamper-proof" generators and fuel	Temporary loss of power generation	May help, but hard to stop determined attack
		Contamination of power plant	Decontaminate, survey to determine level of risk	N/A	None
		Attack on or contamination of plant personnel	If personnel are contaminated with CBRN agents, or if their path to work is impeded by these agents, survey instruments, decontamination, and/or risk assessment may help them travel to work more rapidly	N/A	May help keep vital personnel able to work
Food, water	Water treatment	Loss of water treatment plants	Mitigation efforts will likely use existing technology to protect water supply and processing equipment	Water systems contaminated	Protect inlet points and water source
	Water dist.	Chem., rad, bio contamination	Develop risk assessments to help determine appropriate course of action and decontamination techniques, surveys will help determine which areas (and crops) are affected and require mitigation vs. those that are beyond help	Pipes contaminated by contaminated water	Sensors and active controls in water treatment and distribution systems
	Farms	Chem., rad, bio contamination	Develop risk assessments to help determine appropriate course of action and decontamination techniques, surveys will help determine which areas (and crops) are affected and require mitigation vs. those that are beyond help	Not affected except by loss due to flooding	Can try to protect against contam, but very difficult due to extent of fields – possible air mon?

Food processing plants	Loss of operating power	Mitigation efforts will likely use existing technology – try to prevent loss of power by protecting power plants	Not known	Can install backup generators
	Production line contamination	Survey instruments and protocols to identify extent and severity of contamination, decontamination protocols to expedite cleanup, risk assessments to determine acceptable cleanup levels	N/A (?)	Pre-processing inspection to avoid contam, process line surveys for CBR agents
	Destruction of plant	Mitigation efforts will likely use existing technology	N/A	Enhanced security measures
Hospitals	Loss due to attack	Develop plans to use alternate or field hospitals if necessary, develop methodology for establishing these in a contaminated environment	Lost or hindered due to loss of vital utilities and isolation	Planning will help mitigate the effects of a loss
	Loss of utilities (electrical, phone, data, etc.)	Design more robust hospitals, put critical utilities on upper (possibly "hardened") levels	Most hospitals lost vital utilities	Should help make more resistant to attack
Ambulance	Chem., rad, bio contamination	Contamination control measures, proper PPE for staff and patients, survey to identify least contaminated areas, determine risks to staff, develop plans to limit hospitals to which contaminated patients may be brought	N/A for hurricane	The measures should help hospitals cope with large numbers of contaminated victims
	Staff stay away due to fears of personal safety	Staff education and training will help overcome these fears, as will PPE and easy-to-use survey equipment	Many evacuated or failed to come to work	Education may help – needs further study and work
	Staff delay or deny treatment to contaminated patients	Staff education and training	N/A	Education should help – needs study
	Overwhelmed by "worried well"	Public education programs to reduce numbers, develop handouts for "worried well" that show up, hospital staff training on how to deal with these people, develop robust triage protocols for CBRN agents	N/A	Procedures should help somewhat, but still expect many who do not, or cannot read and heed instructions
	Chem., rad, bio contamination	Develop and train drivers and medics on simple and effective contamination control techniques, and to determine which patients can wait while undergoing decontamination	N/A	Will help, but should still expect contam. Ambulances, patients, & hospitals
	Drivers and medics refuse to care for contaminated patients	Staff education and training	N/A	Will help, but many not take, or remember training

Medical facilities

Area	What are the needs?	Were these (or do we expect these to be) needs in the aftermath of:			
		Hurricane (Katrina, Rita)	**Earthquake (Northridge, Pakistan)**	**"Normal" terrorism**	**CBRN terrorism**
People	Evacuations (before)	Sometimes	Not possible	Sometimes	Probably not
	Evacuation (after)	Eventually	Yes	Yes	Yes
	Refugees	Yes	Yes	Yes	Yes
	Shelter at or near site of disaster	Marginal	Yes	Yes	Maybe
	Food for refugees and residents	Marginal	Yes, marginal	For some	Yes
	Toilet/shower/sink/etc	Marginal	Yes, marginal	No	Yes
	Clothing	Marginal	Yes, marginal	No	Yes
	Routine medical care	Marginal	Yes, marginal	Yes	Yes
	Emergency medical care	Marginal	Yes, marginal	Yes	Yes
	Security/policing	Marginal	Yes, marginal	Yes	Yes
Electric	Loss of electricity (local)	Yes	Yes	Yes	Yes
	Loss of electricity (city-wide)	Yes	No, yes	No	Yes
	Lines down/electrocution hazard	Yes	Yes	Yes	Yes
	Loss of fuel to generating plant	Short-term	No, yes	No	Yes
Food	Stores close or run out of food	Yes	No, yes	No	Yes
	Loss of food transportation	Yes	No, yes	No	Yes
	Spoilage of food	Yes	No, yes	Some	Some
	Refugees and residents lose access to food supplies	Yes	No, yes	Maybe	Some
Medical	Drug spoilage	Yes	No, yes	No	Some
	Loss of drug transportation	Yes	No, yes	No	Maybe
	Closure of hospitals	Yes	Some, yes	Some	some
	Evacuation of badly injured	Marginal	Yes, marginal	Yes	Maybe
Transport	Closure of major roads	Yes	Yes	No	Yes
	Bridge and tunnel closure	Yes	?	Maybe	Yes
	Closure of minor roads	Yes	No, yes	Some	Yes
	Loss of mass transportation capabilities	Yes	No, yes	Some	Yes
	Inability to evacuate after event	Yes	No, yes	No	Yes
	Traffic keeps emergency responders from scene	Yes	No	Maybe	Yes

Chapter 7: The Effects of a Radiological Terrorist Attack

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Introduction

An attack with a radiological dispersal device (RDD, or "dirty bomb") will likely be intended to cause panic, civic and societal disruption, denial of access to valuable property, and financial cost. The terrorists may also wish to cause short-term death from radiation exposure or longer-term health impacts from radiation-induced cancer; however, these effects are less likely.

In the event of a radiological attack, certain actions will be required by regulations, while Protective Action Guides (PAGs) will recommend further actions and limitations. The psychology of those who live, work, or conduct business in affected areas may dictate still more-restrictive precautions at even greater cost. In this paper, we will discuss these concerns, as well as suggesting some activities that may help to mitigate the impact of a radiological attack.

One example – Goiania Brazil

There are no RDD case studies from which we can learn, and there is only one data point that can be used for comparison – the contamination incident in Goiania Brazil. In this incident, an abandoned radiation therapy source was opened by scrap metal dealers with a subsequent spread of contamination. Since neither the scrap metal dealers nor the public understood that radioactive material was present, or the risks of the "pretty" blue powder they found, many people played with the powder, spreading it on their bodies and, in some cases, ingesting it. In the aftermath of the Goiania accident, over 112,000 people voluntarily appeared for radiation screening, about 249 people were contaminated, 151 people were internally contaminated due to ingestion or inhalation of cesium powder, and 5 people died of radiation sickness. Recovering from this accident led to demolishing several tens of homes and removing over 5000 cubic yards of soil, all of which were subsequently disposed of as radioactive waste.

More significant, and longer-lasting were the psycho-social impacts on the citizens of Goiania and other Brazilians with whom they interacted. These will be described in further detail later in this paper.

Radiation exposure and health risks following a radiological attack

Calculating radiation exposures is a relatively simple matter. Real life, however, is bound to be more complex than any calculations performed before an attack. However, it should be possible to calculate both best- and worst-case scenarios for a radiological attack.

In a "dirty bomb" attack, we can expect that the majority of contamination will settle out near to the bomb itself. This will include large particles, clumps of smaller particles that stick together, and particles that adhere to fragments of bomb casing, the vehicle or package holding the bomb, etc. Precipitation will tend to "scrub" smaller particles from the air, calm air (low winds) will

limit dispersal, and even high humidity can help to reduce the spread of radioactivity. This means that we can expect the majority of contamination to settle in a relatively small area close to the weapon itself. For the sake of argument, if we assume that the source used is 1000 Curies of radioactivity (a reasonable size for a research or medical irradiator) and that all of the activity is contained in an area of about 1 acre, calculations show that radiation dose rates in this area will be about 8 rem per hour. This is a very high dose rate, and all persons in this area will reach their legal limit for radiation exposure in less than one hour. However, radiation sickness does not strike until a dose of about 100 rem, meaning that everyone evacuated from this area within a half day should avoid radiation sickness. Radiation exposure begins to become lethal at a dose of about 400 rem, so nobody evacuated within 2 days would be expected to die from short-term radiation exposure. The long-term effects will be described later in this article.

If the majority of activity falls within a relatively small area, we can expect that the majority of contaminated areas will have only low levels of radioactivity. The current limit for contamination is determined primarily by our technological ability to detect radiation rather than by health effects; under current regulations, areas requiring decontamination would produce so little radiation dose as to be nearly unmeasurable with most radiation dose-rate meters. The dose rate from spending 2000 hours annually in such an area would be comparable to that received during a round trip flight from New York to Los Angeles. Although current regulations would require decontaminating these areas, they would pose little to no health risk to those working, shopping, or even living in them.

Dispersal of radioactive materials, with a few specific exceptions, is not likely to pose a short- or long-term health risk to those exposed. Peter Zimmerman, who authored an important study on radiological terrorism, estimates (using what he calls the "Goiania ratio") that deliberately dispersing Cs-137 may lead to up to 150 deaths and 4500 hospitalizations due to radiation injury. This is a large number of casualties from a single attack, although it falls far short of the damage inflicted on September 11, 2001. However, this number of deaths is comparable to what we saw in Oklahoma City and in any number of attacks overseas. Such an attack would be a tragedy, and the impact of such a toll should not be minimized. However, this is very clearly not a weapon of mass destruction.

Many have suggested there might be significant long-term health effects from exposure to radiation from a dirty bomb attack. In particular, some have proposed that up to 1% of those nearest the scene of the attack might die of radiation-induced cancer, and up to 0.1% of those somewhat further from the scene of the attack. Unfortunately, these concerns may be overly pessimistic in that both the Health Physics Society (an international association of radiation safety professionals) and the International Council on Radiation Protection have both issued position papers suggesting that the health risks of large-scale exposure to low levels of radiation may be less than those normally calculated, for reasons given in the following paragraphs. In fact, it is not possible to calculate an estimated number of potential cancer deaths from exposure to radiation from an RDD attack, and the actual number of such deaths is likely to be far lower than the estimates that have been performed.

There is a clear relationship between radiation exposure and cancer induction at high levels of radiation exposure. This relationship is seen in survivors in Hiroshima and Nagasaki as well as

in laboratory animals and human subjects exposed to levels of radiation in excess of 10 rem. However, at lower levels of exposure, the data are far less certain, primarily because the expected number of additional cancers is smaller than the normal variation in "background" cancer incidence. For example, using the radiation dose/cancer induction relationship developed by the National Academy of Sciences, exposing a population of 10,000 people to a dose of 1 rem each (equivalent to about 3 years' of natural radiation exposure) we might expect that 5 people will die of cancer as a result of this radiation exposure. In this same group, we will expect that over 3000 people will develop cancer under any circumstances, and that 1600 of them will die of that cancer. This means that, over 20 years or so (the average amount of time for a cancer to form and grow), we would have to be able to detect the difference between 1600 and 1605 cancers – a nearly impossible task. In fact, we do not know whether or not the relationship that we see at high levels of exposure holds at low radiation dose, so we simply cannot predict the effects of low-level radiation exposure.

The Health Physics Society recognizes this in a position paper issued in 1996 and reissued periodically since. In this paper, HPS feels there is no scientific justification for calculating a risk of cancer from any radiation exposure of less than 5 rem in a short time, or less than 10 rem over a lifetime. The expected radiation dose to the vast majority of those exposed in an RDD attack is likely to be much less than 5 rem.

The ICRP's position is that, if the most highly exposed individual in a population has received a "trivial" dose of radiation then it is appropriate to treat all those exposed as though they, too, received a trivial dose of radiation. As such, the ICRP recommends against calculating the numbers of expected cancers in a large population in which all those exposed have received low levels of radiation. The bottom line is that, while we don't know exactly how many people may eventually get cancer from an RDD attack, the actual numbers are likely to be far fewer than what has been calculated. As one data point, the Chernobyl accident is likely to cause no more than 2000-3000 additional cancers among the population of the Northern Hemisphere during the 50 years following the accident; it seems over-reaching to claim that an RDD attack in one of our major cities will cause more deaths than that accident.

Radiation psychology

The phenomenon of "radiation phobia" has been recognized for many years, causing no little degree of consternation among radiation safety and many medical professionals. Some examples of radiation phobia include:

1. Parents who prefer exploratory surgery or "watchful waiting" rather than permit CT scans or x-rays for their children
2. Physicians who recommend therapeutic abortions following exposure to very minor (and reproductively insignificant) levels of radiation
3. Refusal to consume irradiated foods, in spite of clearly documented health benefits

4. Radiation phobia was responsible for much of the psycho-social aftermath of the Goiania accident and can be expected to be a major factor following a radiological attack in the US. The psycho-social aftermath of the Goiania attack has been described in some detail in a number of documents and will only be summarized here.

As noted above, about 10% of Goiania's inhabitants appeared for radiological screening following the contamination event. In Goiania, contamination was spread incidentally, without malicious intent; a deliberate attack with radiological materials would add the horror of an attack and the psychological impact of radiation phobia, which may well lead to even more people appearing for screening.

We may also assume that untoward fear of radiation may impact remediation efforts, the local economy, and plans to recover use of the affected area. The balance of this section will be devoted to the role that radiation phobia can play in these areas, while their economic impact will be discussed in the following section.

Cleanup and re-occupation

Inevitably, contaminated areas will include places of business, dwellings, or both; and workers, residents, and/or customers must decide whether and when to re-enter the contaminated areas. We must face the possibility that unwarranted fears of radiation may lead these people to insist on unrealistically low remediation standards, and to avoid the affected areas even when remediation is completed. This, in turn, may have a long-term effect on the city and its inhabitants.

Current regulations require an area be decontaminated to acceptable levels before it can be released for unrestricted use. The primary such regulatory guidance, Nuclear Regulatory Commission Regulatory Guide 1.86, was intended use in nuclear power plants and subsequently extended to other radioactive materials licensees and ultimately to any areas or objects contaminated with licensed radioactive materials. At the time this article is being written, it is probable that these same standards would be applied to areas contaminated as the result of a terrorist attack. Unfortunately, these cleanup standards are based on our technological ability to unambiguously detect radioactive contamination and not on the risk posed by this contamination. This is because the intention was to determine the efficacy of decontamination efforts prior to releasing objects for use in "clean" areas, or to determine the propriety of releasing a radioactive materials use area for use by non-radiation workers. In other words, these standards were designed for use by radioactive materials licensees during normal operations in relatively limited areas. They were not designed for circumstances following a radiological attack.

Draft guidelines have been suggested that, if enacted, could change these limits so that they are dose- (and hence risk) based instead of technology-based. If approved, persons living or working in areas affected by a radiological attack would be allowed to receive a radiation dose considerably in excess of that permitted by current regulations (although still considered safe), and it would be possible to allow access to areas with levels of contamination considerably in excess of current limits. If approved, in the immediate aftermath of a radiological attack these guidelines would permit the general public to be exposed to radiation dose rates comparable to those permitted in the 1980s and earlier, which were substantially reduced by later revisions to the radiation safety regulations. In the longer term, these guidelines would call for an "optimization" process, in which affected stakeholders would determine the optimum cleanup level based on many factors, including medical, social, and economic.

Present guidelines for allowable radiation dose are different for radiation workers compared to members of the general public. In the case of radiological terrorist attack today, NRC dose limits to members of the general public would likely be considered appropriate, and would limit individuals to an annual radiation dose of 100 mem from any single source of radiation. The EPA has additional dose limits that apply to nuclear facilities and to radioactive waste repositories; 25 and 15 mrem/yr respectively. EPA and NRC also disagree on radiation dose limits via various exposure pathways, with NRC limiting exposure to 25 mrem/yr from any single exposure pathway (e.g. food, drinking water, etc.), while EPA recommends a dose limit of 15 mrem/yr via the drinking water pathway. These regulatory inconsistencies are confusing and, for all practical purposes, they are differences that will have little or no impact on the actual health risks faced by those exposed. Through the Federal Emergency Management Agency (FEMA), the Department of Homeland Security has developed post-attack radiological contamination guidelines that would help to resolve this matter. However, as of this writing, these guidelines (shown in part below) have not been adopted.

Phase	Protective Action	Protective Action Guide	Reference
Early	Limit Emergency Worker Exposure	5 rem (or greater under exceptional circumstances)	EPA PAG Manual
	Sheltering of Public	1 to 5 rem projected dose	EPA PAG Manual
	Evacuation of Public	1 to 5 rem projected dose	EPA PAG Manual
		10 rem projected dose	New DHS guidelines
Intermediate	Limit Worker Exposure	5 rem/yr	See Appendix 1 of recommended guidance document
	Relocation of General Public	2 rem projected dose first yr Subsequent years: 500 mrem/yr projected dose	EPA PAG Manual
	Food Interdiction	500 mrem/yr projected dose	FDA Guidance
	Drinking Water Interdiction	500 mrem/yr dose	EPA guidance in development
Late	Final Cleanup Actions	Late phase PAG based on optimization	FEMA recommended guidance document

Economic impact

The accident in Goiania also affected the area's economy because agricultural products and other goods from the Goiania area lost their appeal outside the area. Many Brazilians preferred to purchase foods and goods from other parts of the country not involved in a contamination incident, even after cleanup was completed. By extension, we may assume that there may be a similar impact on any city attacked with radiological weapons. In addition to the impact on the sales of local products, we may also anticipate drops in tourism, conventions, attendance at

cultural events (e.g. concerts, theater, museum shows, etc.), and other events that bring people in from out-of-town. Since many large cities draw visitors from wide areas for these events as well as for shopping, the economic impact may be substantial. This is particularly likely to be true in the first months, or even years following an attack, when the memory of the attack is fresh and cleanup activities are taking place. This constant reminder of radioactive contamination, coupled with continuing news coverage, is likely to continue to impact the local economy for an extended period of time – perhaps even after cleanup is complete and access to affected areas is restored. If cleanup standards are relaxed to be risk-based instead of technology-based, we also face the possibility that anti-nuclear and environmental groups, perhaps in conjunction with elected and unelected officials, may protest this relaxation – possibly out of a combination of genuine concern for perceived health risks, the opportunity to gain publicity, to advance their personal or organizational agenda, or for other reasons.

While the immediate health impact of an RDD attack may be fairly limited, there is wide agreement that the radioactivity may be widely spread, with the extent of the spread depending on weather conditions, the size of the explosion (if a bomb is used), the dispersibility of the radioactive materials used, and other factors. "Ideally" distributed, a single Curie of radioactivity (the amount of radioactivity in a well-logging source used in the mining or petroleum industry) can contaminate several thousand acres to the point of requiring remediation under current standards. Several have noted that this can have a tremendous economic impact in terms of the loss of access to so large an area as well the direct and indirect cleanup costs.

On the other hand, a radiological attack will require remediation, probably on a large scale. While this will be expensive, much of the cost is likely to be borne by the federal government, reducing the direct financial impact on the city and businesses in the affected area. Remediation efforts may cost up to hundreds of billions of dollars, much of which will be spent on remediation workers' salaries and their needs (food, lodging, clothing, etc.), on supplies (fuel, basic construction supplies, vehicles, etc.), and on local subcontractors. Although profits, radioactive waste transportation and disposal costs, and some specialty supplies (e.g. radiation detectors, anti-contamination clothing) may be paid to out-of-town companies, a great deal of remediation expenses will likely end up being spent in the city that was attacked. This will not be able to save those businesses that are located in the contaminated area, but may help to mitigate the economic impact on the city as a whole while remediation efforts are in progress.

We may also anticipate that a radiological attack may cause many residents to move, and many remaining residents to avoid the area that was attacked. These factors can be expected to lead to a reduction in the number of tenants and/or buyers, and a reduction in prices for both commercial and residential real estate markets; particularly in cities with surpluses in these markets. On a city-wide basis, the drop in real estate value in the immediately affected area may be countered by a concomitant increase in real estate values elsewhere, particularly if housing or office space is limited. However, these increases will not help the area directly affected, and may not help the economics of the city itself if available space is outside of city limits.

Another way to approach this is that of Becker and Rubinstein, who studied the economic effects of terrorist attacks in Israel. They note that people who are habituated to certain behaviors tend to continue these behaviors, even in the aftermath of a terrorist attack while those who are not

tend to avoid the site of a terrorist attack. For example, they note that bus drivers and airline pilots continue to drive and fly following a terrorist attack, and that they continue to convey regular passengers to their destinations. However, overall bus and airline traffic drops following an attack because of the large number of passengers who are less dependent on these modes of travel. In other words, people who do not have cars continue to take the bus, as do people who are accustomed to taking the bus daily. Others, those who take the bus only occasionally but who have alternate transportation available, may stop riding the bus in the aftermath of a suicide bombing of a city bus. Similarly, they note that heavy beef eaters do not change their eating habits in the aftermath of a "mad cow disease" scare, while occasional beef eaters reduce their beef consumption.

Extending this to the scene of a terrorist attack, we can expect that those who work in the affected area will return to work, provided they are permitted to enter the area, that their fears do not overwhelm them, that they have a place of business to return to, and that they cannot (or do not choose to) find employment elsewhere. We can expect similar behavior of others whose daily routine takes them into affected areas. However, behaviors can change with time; if an area is inaccessible, or only inconveniently accessible (requiring a long detour, protective equipment, whole-body scanning, etc.) for a prolonged period of time, even the most habitual of patrons or workers will have the opportunity to develop other habits. This could serve to worsen the economic impact in the affected area.

Factors affecting the impact of a radiological terrorist attack

First, and most importantly, we must recognize that a radiological attack is not likely to cause casualties on the scale of the September 11, 2001 terrorist attacks. Many radiation safety professionals have calculated radiation dose rates from a variety of radiological attack scenarios and feel that the radiation dose to which the public may be exposed, while elevated, will not be sufficiently elevated as to cause short-term deaths through radiation sickness or long-term deaths via cancer (see Karam 2005 for a summary). The worst case scenario is that postulated by Peter Zimmerman (2005) based on the experience in Goiania Brazil. Zimmerman's estimates are that a well-executed radiological terrorist attack may leave over 150 dead and up to 4500 requiring medical attention. There is no denying that this would be a significant toll, there is also no denying that this would pale in comparison with that of the September 11 attacks.

In addition to the immediate and long-term health impact of a radiological attack, we must also consider the property impact. To assess this, we must consider factors that include:

1. ***Weather at the time of an att***ack. Precipitation will wash contamination from the air and will reduce the contamination zone, but will complicate emergency response efforts. Heavy winds can spread a plume over a larger area. Buildings may draw less air from the outside during very hot or very cold weather.
    a. Weather is beyond our control. Terrorist groups may select specific weather conditions for their attack.
2. ***Clean-up standards for radiological decontamination***. Stringent clean-up standards will cause higher initial costs, but may make residents and tenants more likely to re-occupy an area following decontamination. More relaxed standards may reduce initial costs, but may cause long-term vacancy and reduced property values.

3. ***Psychological impact on residents and visitors***. A horrific attack may leave lasting psychological scars, even with only a minor radiological component. Lack of candor by government officials may cause lingering concerns or suspicions that crucial health-related "facts" are being hidden. An unprepared public that is terrified of radiation may avoid areas that would be visited by those with a higher degree of understanding. Requiring overtly visible or inconvenient safety precautions (e.g. donning shoe covers or breathing masks) would encourage further worries and would likely lead to avoidance of the contaminated area(s) by the general public.
4. ***Heating, ventilation, and air conditioning (HVAC) characteristics of affected buildings***. A building whose HVAC intake vents are in the path of a plume may have contamination spread throughout the ventilation system and building interior, requiring extensive cleanup or even demolition. Radioactive contamination can be blown into buildings (or parts of buildings) by a breeze; if building windows are typically open to admit a breeze, or if there is typically a gust of air into the lobby when the main door is opened, there is also the probability of contamination if that gust of wind contains radioactivity.

Mitigating the effects of an attack during the emergency and recovery phases

Some actions can be taken to help mitigate the effects of a radiological attack. These are discussed briefly below.

It may be possible to develop remediation standards that are sensitive to risk, cost, and public fears. For example, it may be possible to pave over a contaminated street, rather than tearing up asphalt for disposal as radioactive waste. Similarly, it may be possible to clean only the first few stories of a building's exterior (even if contamination extends further) because contamination at higher elevations will cause no discernable impact at street level, or in the building's interior. Finally, we should recognize that not all areas require identical restrictions; for example, residences, hospitals, schools, and nursing homes should have more restrictive limits than warehouses or industrial workplaces.

In keeping with the above comments, it may be appropriate to develop a series of decontamination standards that are consistent with various uses and occupancy factors over long periods of time. For example, if we are to allow the general public to be exposed to radiation levels of 15, 25, 100, or 500 mrem annually from cobalt-60 contamination (this is considered a likely RDD isotope), the following levels of contamination would be permitted in various settings:

Setting and annual occupancy	**Allowable contamination levels (dpm/100 cm^2)**				
	15 mr/yr	**25 mr/yr**	**100 mr/yr**	**500 mr/yr**	**2 rem/yr**
Residential (100% occupancy)	1200	2000	8000	40.000	160,000
Workplace (2000 hours occupancy)	5200	8700	34,800	174,000	696,000
Warehouse (200 hours occupancy)	52,000	87,000	348,000	1,740,000	6,960,000

Note: Present guidance permits up to 1000 dpm/100 cm^2 of removable contamination with up to 5000 dpm/100 cm^2 of fixed plus removable contamination for Co-60, Cs-137, and other beta-gamma emitting radioactive isotopes.

These would be modified depending on the specific isotope because each different gamma-emitting isotope has a different factor. For example, cesium-137 contamination emits ¼ the amount of radiation as an equal amount of cobalt-60, so a dose-based decontamination standard would allow four times as much Cs-137 contamination as the levels noted above. Allowable contamination levels for alpha radiation-emitting might differ significantly because, with alpha radiation, the primary concern would be inhalation of resuspended radioactivity rather than exposure to external radiation.

The public has an exaggerated fear of radiation. However, like many phobias, the truly fearful are relatively small in number (although very vocal). My experience is that the majority of the public may be concerned, but they are willing to be convinced that their fears are overblown. Having said that, minimizing the psychological impact of a radiological attack will require undoing the work of decades of conditioning to the contrary, and ideally this work should begin immediately. Educating the public in a fact-based fashion is an essential part of trying to mitigate unreasonable fears of radiation, and this should begin immediately rather than on the day of an attack. We should also carefully examine the manner in which we respond to minor amounts of contamination – contamination in excess of regulatory limits but posing no physical danger – as requiring stringent precautions for biologically trivial levels of contamination will only serve to heighten public fears. However, a full treatment of this subject is sufficiently involved as to warrant a full article.

We should strive to educate physicians and other health care professionals in the effects of exposure to radiation and radioactivity. This will help them to act appropriately in the event of a radiological or nuclear emergency. It will also help them to provide scientifically accurate information to their patients on a daily basis, which will not only better serve their patients now, but may also help their patients better understand the actual risks they might face in the event of a radiological attack. People tend to believe their physicians; this can give physicians a vital role in helping educate the public, and may help to mitigate the psychological effects of a radiological attack, should one occur.

Ventilation systems with inlets substantially above ground level will be less susceptible to drawing in contaminated air and spreading it throughout the building. Ventilation systems that rely on recirculated air while running the furnace or air conditioning will also be less susceptible to spreading contamination through the building. Keeping windows shut, especially on lower levels, will help to reduce the risk of contamination blowing into a building, although this may not be practical in buildings that lack air conditioning or in which the residents or tenants enjoy fresh air. Internal building safety procedures may be developed requiring all windows and doors be shut in the event of any untoward incident. Similarly, it is not possible to bar people from a building, but it may be possible to adjust ventilation so that the building lobby is maintained at a higher pressure than outside (that is, so a breeze blows out the door when it's opened). Such measures can help to minimize the spread of contamination into a building, reducing the later

need to decontaminate the ventilation system and interior spaces. New buildings can be designed with these factors in mind to minimize the spread of contamination.

It may also be possible to design buildings, and especially HVAC systems, to help reduce the cost of remediation. For example, inserting HEPA filters at the inlet to an HVAC system, the majority of radioactive contamination would be excluded from the building's interior. This, in turn, could substantially reduce remediation costs following an RDD attack, while simultaneously helping to protect the inhabitants from inhaled radioactivity. Another approach might be to design ventilation system ducts with large access holes to ease contamination surveys, relatively short sections of duct to reduce the removal of "clean" ducting, and possibly strippable internal coatings to help reduce the volume of radioactive waste generated during remediation. Other design features may include placing ventilation intakes as high above the street as possible, maintaining stairwells and lobbies at a slight positive pressure, or sealing windows on the first few floors. There are undoubtedly other measures that can be built into new facilities. It is worth noting that some of these actions may serve to improve interior air quality under any circumstances, or in the event of biological or chemical attack. This, in turn, may be used as a selling point to attract tenants, who may even be willing to pay slightly higher rates for the privilege of living or working in a building designed to offer added protection to its inhabitants.

Summary and conclusions

We have lived for several years with the knowledge that terrorist organizations are interested in launching a radiological attack against the US or our allies. If such an attack is successfully launched, lives will probably be lost, although far fewer than were lost in the attacks of September 11, 2001. However, such an attack can still be quite costly in terms of clean-up costs, loss of access to affected areas, and the psychological impact of radiation fears.

There are actions that we can take to help mitigate some of the impact of a radiological attack. Some of these have been suggested in this document, and there are undoubtedly others. Although there is a cost associated with each of these actions, the cost might be offset by reduced cleanup costs following an attack, improved air quality (and, hence, health) for a building's residents/tenants, or by the perceived benefits of living or working in a safer building.

Finally, many actions and much of the cost of recovery will be driven by a combination of regulatory requirements and the public's perception of radiation. Even loosening regulatory restrictions somewhat may not lessen the overall economic impact of an attack if the public remains unconvinced that an area is safe to re-enter. Accordingly, we must not only try to arrive at risk-based regulations, but we must also work to educate the public so that they will have a better understanding of these risks and how they compare to other risks we face daily.

Chapter 8: The Effects of Nuclear Terrorism

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Introduction

As seen in Hiroshima and Nagasaki, nuclear weapons are devastating and a nuclear attack in a major city could kill hundreds of thousands of people and destroy buildings over a large area. In the immediate area of the explosion, the fireball will incinerate and vaporize buildings and those in them. Further away, thermal and blast effects will cause further destruction and deaths, and the radius of this will depend on the size of the weapon, geography, and other factors. Even further afield, beyond the zone of lethality, fallout will spread radioactive contamination, complicating recovery efforts. A common conception is that, in the aftermath of a nuclear attack, a city is likely to be an uninhabitable nuclear wasteland. Reality is somewhat more complicated, and the purpose of this article is to examine some of these complicating factors. In particular, we must recognize that the extent of radiological effects (contamination, long-term elevated radiation dose rate) will be much greater than the extent of destruction from the nuclear blast. In other words, a nuclear attack will produce problems very similar to those caused by a radiological attack once we look beyond the zone of utter destruction.

Nuclear weapon effects

Some atoms (fissionable isotopes of uranium and plutonium, for example) fission readily when struck by neutrons, releasing a great deal of energy. The amount of energy released depends on the number of fissions that take place so, in general, a larger amount of fissionable material will produce a larger number of fissions and a larger explosion. A minimum amount of fissionable material is needed to make a nuclear weapon – a critical mass – this is the amount of material needed to sustain the chain reaction that causes the explosion. A critical mass of fissionable uranium (U-235) is about 20 kg, and a critical mass of plutonium is about 10 kg. Fission (nuclear) weapons release energy by splitting large atoms; thermonuclear (fusion) weapons release energy by fusing light atoms such as tritium (a radioactive isotope of hydrogen). Fusion requires exceptionally high temperatures and pressures; these are produced by a fission device that acts as a trigger for the fusion part of the explosion.

Energy is released during the explosion; about 200 million electron volts (MeV) for each fission. If every atom in a critical mass of U-235 were to fission (about $5x10^{25}$ atoms), the energy released would be equivalent to nearly 400 kilotons of TNT, or over 450,000 megawatt-hours of energy. In fact, this amount of uranium in a nuclear weapon will release about 15-20 kt of energy, which is reasonable because a large fraction of the atoms will not fission. Gamma rays are also produced by fission, generating very high radiation levels at the time of the explosion itself. This energy is released in a very small fraction of a second. The energy released creates a fireball that ionizes the air and vaporizing everything within the fireball. This energy release

also creates a thermal pulse sufficient to ignite fires at a great distance, and an over-pressure shock wave capable of causing great destruction at a distance from the detonation.

When uranium or plutonium atoms fission they split into two radioactive atoms called fission fragments. A 20 kt explosion results from the fissioning of about 2.5×10^{24} atoms and produces about 5×10^{24} fission product atoms. The amount of radioactivity this represents will change with time because, as short-lived fission products decay to their longer-lived progeny, the radioactive decay rate drops proportionately. In the near-term aftermath of an explosion, the amount of radioactivity produced is several tens of millions of Curies. This is several thousand times the amount of radioactivity found in many research and sterilization irradiators that have been postulated as radiological weapons.

All of these effects will vary according to the strength of the device and the distance from the point of detonation. The strength of the blast wave and the thermal pulse drop with the square of the distance to the explosion – doubling the distance reduces these by a factor of 4. Radiation levels from the explosion also drop with distance according to the inverse square law. All of these factors scale directly with the device yield, so doubling the yield doubles the radiation levels, thermal pulse, blast overpressure, and the amount of fallout produced.

Yet another factor affecting nuclear weapons effects is the altitude of the explosion. Overpressure from surface burst (when a nuclear weapon is detonated at or very near ground level) is about 60% that of an airburst detonated at 1700 feet above ground, while the thermal effects of a surface burst are about 75% as severe as those from a burst at this altitude. This is why the Hiroshima and Nagasaki devices were detonated as airbursts – to maximize the destruction caused by blast and thermal effects.

Very significantly, the altitude of a detonation has a dramatic effect on the amount of fallout produced by a nuclear explosion. Whatever materials are within the volume of the fireball will be vaporized. As the fireball expands and cools, these materials will begin to condense and, as they do so, the radioactive fission products become incorporated into the condensing particles and they fall back to earth as fallout. As the altitude increases, the amount of material incorporated into the fireball drops, and the amount of fallout decreases.

We must remember that, although there will be massive loss of life and destruction up to a distance of a few miles from a surface burst in the range of a few tens of kt (the size of the Hiroshima and Nagasaki weapons), most of our cities are far larger than this. This means that we can expect that most of a major city will survive a nuclear attack. We must also remember that many millions of curies of radioactive fallout will be generated, and this will spread far beyond the range of destruction; once we progress beyond the radius of destruction we should expect to see wide-spread radioactive contamination, possibly to great distances from the site of the attack. In this respect, at a certain distance, a nuclear attack may resemble a very high-activity RDD ("dirty bomb") attack. The rest of this paper will address some of the radiological and other effects of a nuclear terrorist attack on a major city.

Description of problem

Lawrence Livermore National Laboratory has developed and released a computer code called "Hotspot" (http://www.llnl.gov/nai/technologies/hotspot/) that provides a first-order approximation of the effects of radiological and nuclear weapons. Several Hotspot runs were made, assuming a 20 kt nuclear weapon detonated as a surface burst with winds blowing along the long axis of the island from south to north at a speed of about 15 mph. For the sake of simplicity, I have assumed the target city is New York City, and that the device is exploded in front of the New York Stock Exchange. The following table summarizes the radiological, blast and thermal effects at distances of ½, 1, 2, 5, and 10 miles from the location of the explosion. The values for immediate radiation levels, thermal energy, and blast overpressure came from the Effects of Atomic Weapons calculator (Glasstone 1977) and the 1-year radiation dose was calculated using Hotspot. The fireball from this explosion will be nearly 1000 feet in diameter, and everything within this radius is assumed to be utterly destroyed.

Hazard	**50% lethal**	**100% lethal**	**Fatality radius (feet)**	**Injury radius (feet)**
Prompt radiation (rem)	450	1000	5000 (50% lethal)	9000 (radiation sickness)
Thermal (cal/cm2)	23	32	3000 (50% lethal burns)	9000 (3rd degree burns)
Blast pressure (psi)	65	90	1100	10,500

Radius for various nuclear weapons effects (fatality and injury). Calculated using Effects of Nuclear Weapons circular slide rule (Glasstone and Dolan 1977).

Distance (miles)	**Landmark(s)**	**Radiation dose from blast (rem)**	**Fallout: 1-year radiation dose (rem)**	**Thermal (calories per cm2)**	**Blast (psi)**
½	City Hall	1430	20,000+ along plume centerline	40	11
1	Chinatown	220		9.4	3.4
2	Washington Square Park, NYU	0.2		2.2	1.0
5	Central Park Mall (about 1 mile past Times Square)	Negligible	4000+ along plume centerline	0.2	Negligible
10	Harlem, City College of CUNY	Negligible	1400+ along centerline	0.03	Negligible

Effects of a 20 kt surface burst at selected distances from detonation site. Calculated using Effects of Nuclear Weapons circular slide rule (Glasstone and Dolan 1977).

Another way to view the problem is the area contained within various dose contours. For example, recent federal guidance suggests that it may be acceptable to receive a radiation dose of up to 10 rem annually following an RDD attack. If we apply this same standard to radiation dose from fallout following a nuclear attack, Hotspot tells us that nearly 600 square miles will be contaminated to this level (people in an area of about 100 square miles will receive a radiation

dose of 100 rem/yr, and an area of almost 8 square miles will have a radiation dose of 1000 rem/yr). This plume would extend to a distance of about 95 miles (reaching Hartford Connecticut) from the point of the attack and would be up to 10 miles across at its maximum width (about 40-50 miles downwind). Extending this further, we find that an area of almost 2000 square miles (reaching over 150 miles) will be contaminated to the point of giving an annual dose rate of 1 rem/yr, and an area of 3000 square miles (extending over 200 miles – beyond Boston) will have an annual dose rate of more than 100 mrem (the allowable dose to the general public). Although this level of exposure is not dangerous and does not call for remediation on account of health effects, it will result in very noticeable contamination levels that are significantly in excess of those allowed in uncontrolled areas under non-emergency circumstances today. This makes it very clear that the areas affected by radiological contamination are significantly larger than those that would be destroyed by the blast itself. In other words, beyond the area affected by the blast, a nuclear attack will have a great deal in common with an RDD attack, and both contamination and the resulting radiation dose must be considered as a part of the emergency response. One reason that contamination was not considered as significant in the aftermath of the attacks on Hiroshima and Nagasaki is that airbursts tend to inject fission products into the atmosphere and, in the absence of particles that would carry the fallout back to earth, the plume largely dispersed into the atmosphere and/or drifted out to sea, depositing little contamination on the ground.

- ***Effects of weather***

The Hotspot calculations discussed above assume that an attack will take place in good weather with a 15 mph wind blowing along the length of Manhattan. However, in real life, the weather is more variable and is unlikely to cooperate with either terrorists or citizens. Weather is unpredictable, and can have a significant impact on fallout patterns and the resulting radiation exposure. Precipitation, for example, will help to "scrub" fallout particles from the air, leading to a smaller plume with higher levels of radiation and contamination close to the site of the explosion.

Summary of nuclear weapon effects

- ***Immediate impact***

In the immediate aftermath of a 20 kt surface burst, more than half of the exposed population will be expected to die of blast, thermal, or radiation effects to a distance of nearly 1 mile and we should expect to see injuries to a distance of nearly 2 miles. This means that the area in which the blast will be fatal is almost 1 square mile, and there will be serious injuries across an area of about 3 square miles.

Because a surface burst will create a very large amount of fallout, prevailing winds will carry a radioactive plume, which will settle according to the size and density of the particles in the plume and the weather conditions. While parts of the plume may circle the globe, most of the particles will settle to the ground within several hours and within several tens of miles.

- ***Long-term radiological impact***

In the immediate vicinity of the attack (within the radius of destruction) we will see very high radiation dose rates and exceptionally high levels of contamination. Radiation levels will exceed those of currently suggested Protective Action Guides (100 rem in 1 year) to a distance of about 45 miles, forcing evacuation of nearly 100 square miles until decontamination or radioactive decay reduce these to more acceptable levels. When we consider the effects of elevated levels of radioactive contamination (even if radiation dose rates are considered acceptable) and the spread of this contamination into the environment, it is likely that extensive areas will be significantly impacted by even a single nuclear weapon.

The long-term health impacts are more difficult to predict because there is still substantial disagreement on the effects of exposure to somewhat elevated radiation levels. Current guidance from the National Academy of Sciences, the United Nations Science Committee on the Effects of Atomic Radiation, the National Council on Radiation Protection and Measurements, and the International Council on Radiation Protection holds that any exposure to radiation levels in excess of natural background radiation carries with it some level of risk, and that this risk rises in direct proportion to the radiation dose received. Under this model, we would expect that up to 25% of those exposed to a dose of 10 rem per year for 50 years may eventually die of radiation-induced cancer. According to this model, then, 2.5% of those exposed to 1 rem/yr for 50 years would be expected to succumb to cancer, and the risk from other exposures would scale accordingly. However, there are uncertainties in this model, and it is likely that many factors would serve to reduce the cancer mortality from these predictions.

Response and recovery outside of the zone of destruction

As we have seen, in addition to the destruction caused by a nuclear detonation, radioactive fallout – contamination – will be deposited across a very large area; hundreds of square miles beneath a plume that may extend for more than 100 miles from the point of the attack. Radiation levels from this contamination will range from elevated to dangerously high, and very high contamination levels are likely to be found both outside and inside of buildings that are exposed to the plume.

In an earlier article I discussed many of the effects of a radiological attack against a major city; most of the effects mentioned in this article will be present in a nuclear attack. However, these effects will be much more extreme and their impact will be exacerbated by the destruction, death, and shock caused by a nuclear attack; and the risk of radiation injury will be substantially elevated compared to an RDD attack to a distance of several tens of miles. In the following sections, we will examine, at a variety of distances from the site of a nuclear explosion, the effects we expect to see and how these may be expected to affect response and recovery efforts.

- ***½ mile (New York City Hall)***

The fireball from a 20 kt explosion will be nearly 1000 feet in radius, so people at a distance of ½ mile will be about 1500 feet beyond its edge. People at this distance will receive a fatal radiation dose, which would lead to death in a period of days to weeks. However, the thermal pulse will be fatal in a far shorter period of time, and many injuries – including many fatal

injuries – will be caused by flying debris and collapsing structures. There may be some survivors among people at this distance if they are shielded from the direct effects of the explosion; those people who are below-ground (in basements or subway tunnels, for example) or those who are behind large buildings may be shielded from radiation, thermal, and blast effects if the structures that protect them do not collapse. This means that survivors at this distance may be buried beneath debris.

Many, if not all utility lines at this distance are likely to be ruptured or cut, and electronics (including cell phone towers) will likely be incapacitated by the electromagnetic pulse accompanying the explosion. Fires will likely be ignited by the thermal pulse, and firestorms may extend to this distance and beyond, fed by ruptured gas lines, furniture, paper, and other flammable objects.

Within the fallout plume, radiation levels are likely to be dangerously high – several thousand rem per hour for the first several hours after the explosion. These high levels of radiation will prevent emergency responders from being able to rescue survivors, and it may not be possible to rescue those who are trapped in basements or subway tunnels unless it is possible to launch rescue attempts belowground. The fallout plume may be narrow, depending on the exact wind patterns in a complicated urban environment; radiation dose rates may drop dramatically over a space of only a few hundred yards and, even a few blocks away from the plume centerline, radiation levels may be acceptable to permit rescue attempts. Alternately, such survivors may be able to self-evacuate if the basements and tunnels do not collapse. However, rescue attempts at this distance should be discouraged unless the rescue team is accompanied by a radiological survey team and agrees to abandon rescue efforts when radiation dose to any rescue team member reaches pre-determined levels (e.g. 50 or 100 rem, as determined by the incident commander or on-site radiation safety or health and safety personnel).

Long-term recovery efforts will depend critically on the amount of contamination present, the extent of the damage, and residual radiation levels. It is likely that a surface burst will deposit very high levels of radioactive contamination in this area and, while radiation levels will decay fairly rapidly, radiation levels at this distance from the explosion site are likely to remain very high for months following the explosion. This is likely to complicate recovery efforts, especially in the first months or years following the attack. Radiation and contamination levels may make it difficult to repair utility lines, structures, and roads in this area, and it may be necessary to consider bypassing these at first, until radioactive decay and decontamination reduce radiation and contamination to levels that will permit prolonged work.

- ***1 mile (Chinatown)***

At a distance of 1 mile from the site of a 20 kt explosion only about 5% of those exposed will receive a lethal dose of radiation, while everyone exposed will develop radiation sickness. Most of those exposed will also receive 3rd degree burns, and there will likely be injuries from flying debris and from structures that are damaged by the blast. However, at this distance, there may be many more survivors underground or behind large buildings that shield them from the direct weapon effects. Buildings at this distance are likely to have windows blown out, contaminating the interiors with radioactive fallout.

Radiation levels in the immediate aftermath of the explosion will be dangerously high – in excess of 5000 rem per hour – which will make rescue operations in the path of the plume too dangerous to pursue, although radiation levels drop dramatically outside of the plume to less than 10 rem/hr at a distance of only 200 yards or so from the plume centerline. As such, although radiation dose rates may make it impossible to attempt rescue of persons within the fallout plume, those who are just a few hundred yards away may be able to be rescued without risk.

As at ½ mile, long-term recovery efforts will be complicated by the presence of very high levels of radioactive contamination and annual radiation dose to workers, especially to those working in the fallout plume. The exact shape and extent of the plume will be complicated and will depend on the urban geometry and the weather, and on the stability of the wind direction. If the wind blows steadily in the same direction for many hours, the plume is less likely to spread. It may be possible to commence recovery efforts almost immediately after the emergency phase is over for all areas outside of the plume.

- ***2 miles (New York University, Washington Square Park)***

Radiation levels from the explosion itself will be measurable, but far too low to cause radiation sickness or injury. Those with a direct line of sight to the explosion may suffer up to 3rd degree burns, and many may also be injured by flying debris and other blast-related effects. However, at this distance, it is likely that most building will survive, and buildings with blast-resistant glass and other active and passive protection features may be protected from large-scale contamination.

Along the plume centerline and to a distance of a few hundred yards from the centerline, radiation levels remain dangerously high in the immediate aftermath of the explosion, although the highest-dose part of the plume is narrowing at this distance. Most of the people in these areas should survive the explosion and many should be able to self-evacuate, although many may require rescue due to burns and blast-related injuries. Although radiation from the blast itself will not be dangerous, radiation dose rates from fallout is expected to be fatal to those who remain in the fallout plume for more than a short period of time. This will continue to make rescue operations dangerous and, even at this distance from the site of the explosion, it may be necessary to limit rescue operations in the most heavily-contaminated areas. In fact, there may be up to 2 or 3 square miles in which radiation levels will remain too high to permit rescue and recovery operations to take place during the first days following the attack. Those persons who are outside and who cannot self-evacuate will likely receive a lethal radiation dose, although those who are inside or who can find shelter inside of buildings that are designed to exclude contamination are likely to remain safe during this time.

Long-term recovery efforts at this distance from the explosion will depend on fallout deposition. Those areas that are not contaminated are likely to have minor to moderate damage, and recovery efforts may be fairly straight-forward. Similarly, lightly contaminated areas and the interiors of buildings that employ protective features may possible to decontaminate in a fairly straight-forward manner; the use of passive and active protective features (e.g. blast-resistant glass, protected ventilation systems, etc.) should help to facilitate recovery. However, more heavily

contaminated areas will remain off limits until radiation dose rates drop to acceptable levels, either via radioactive decay, decontamination, or a combination of these factors.

- ***5 miles (Central Park Mall)***

At a distance of five miles from the site of the explosion, the prompt radiation dose rate, blast pressure, and thermal effects will be negligible. At this distance, EMP effects may begin to attenuate, allowing the use of undamaged cell phones, radios, computers, and other electronic devices.

While there will still be extensive fallout and exceptionally high levels of contamination, radiation levels from fallout will not be dangerous and should not hinder rescue efforts at this distance.

Long-term recovery efforts in areas directly impacted by the fallout plume will be hampered by the presence of significant (from a regulatory standpoint) radiation dose rates and high levels of contamination. However, buildings with active and passive protection should be protected from much of this contamination and should be returned to full service more rapidly than unprotected buildings.

- ***10 miles (Harlem, City College)***

Radiation, blast, and thermal effects are unimportant at this distance.

The deposition of fallout will cause elevated radiation levels and contamination levels will continue to be extremely high. While this may complicate recovery, it should not affect whatever emergency response efforts may be necessary.

Long-term recovery will continue to be complicated by the presence of high levels of contamination. Even at this distance, long-term radiation levels along the plume centerline may continue to be so high as to preclude living in this area until decontamination or radioactive decay has reduced radiation levels to acceptable levels.

- ***85 miles***

Long-term recovery will still be complicated by the effects of fallout deposition, which will raise radiation dose rates to about 10 rem in the first year post-attack. This is the maximum dose rate considered potentially acceptable under recently released guidelines.

- ***200+ miles***

Radiation dose rates in the fallout plume have finally dropped to less than 100 mrem (0.1 rem) in the first year post-attack. Contamination levels remain significantly higher than those considered acceptable for the release of a contaminated area for unrestricted use. However, this limit (1000 disintegrations per minute over an area of about 4”x4”) is intended for use by radioactive

materials licensees and it has no health and safety basis; as such, this limit may not be applicable or useful following a terrorist attack.

Summary and conclusions

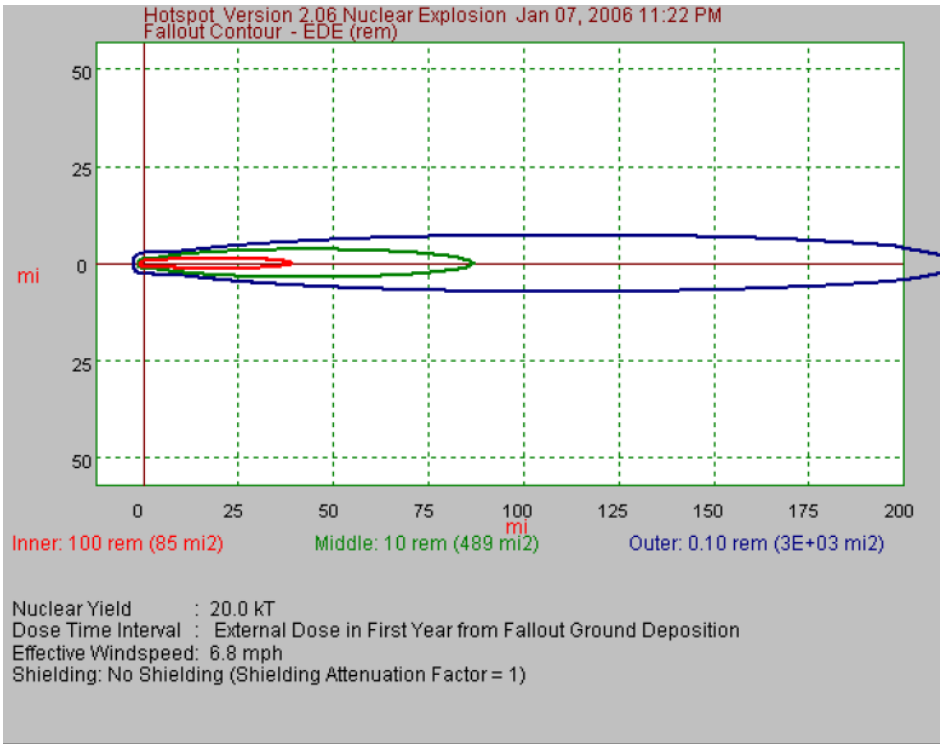
A terrorist attack using a nuclear weapon will have horrific effects for those who are within a few miles of the attack. Radiation, blast, and thermal effects will be fatal to a distance of at least one mile, and may cause injuries to a distance of nearly 2 miles. Even at greater distances, radiation dose rates from fallout deposition will be so high as to prevent rescue and recovery efforts. However, persons who are sheltered, particularly inside of buildings designed to exclude radioactive contamination from the interior, may remain safe until they can self-evacuate. In addition, if weather conditions remain stable, the fallout plume should remain relatively narrow, making it possible to safely perform rescue operations within a few hundred yards of areas with potentially lethal levels of radiation. Radiation levels will remain sufficiently high to prevent reoccupying contaminated areas to as far as 35 miles from the scene of the attack in the direction of prevailing winds, and radioactive contamination may cause radiation dose rates in excess of those permitted to the general public to a distance of 140 miles or so. Contamination levels may exceed those permitted in an uncontrolled area to much greater distances.

It may be necessary to restrain emergency responders from entering areas with dangerously high radiation levels, in favor of concentrating their efforts on those victims who will survive, and in order to retain the responders' ability to continue working in good health.

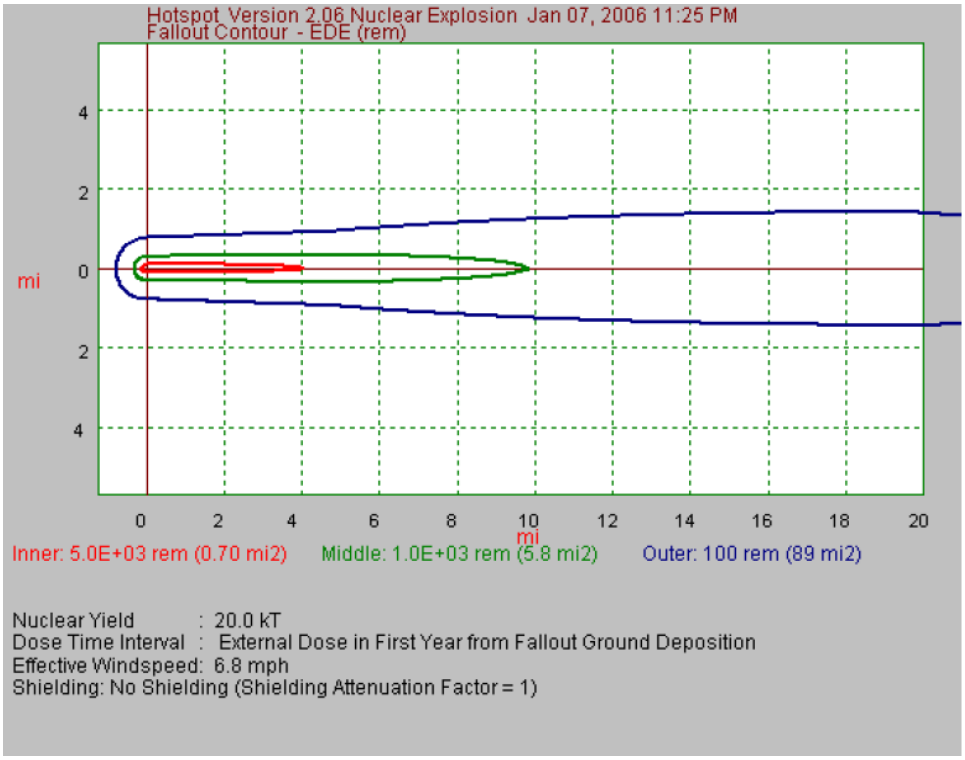
Long-term recovery efforts will depend on the amount of fallout deposited, the position of the fallout plume, and the presence or absence of protective measures in existence at the time of the attack. Facilities that utilize active and passive protective features should have lower levels of interior contamination, offering higher levels of protection to building inhabitants and reducing decontamination and recovery costs.

Plots

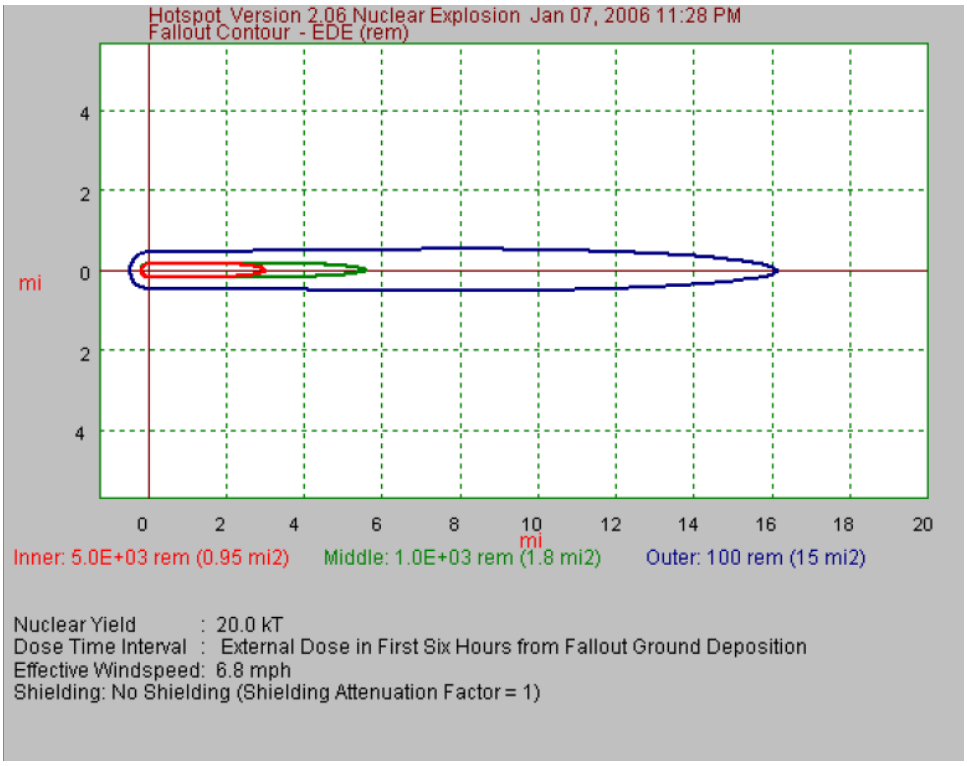
Graphics: The following plots are all from Hotspot. All assume identical beginning conditions; the only difference is the amount of time over which the exposure takes place and the degree of shielding from structures or by being underground.



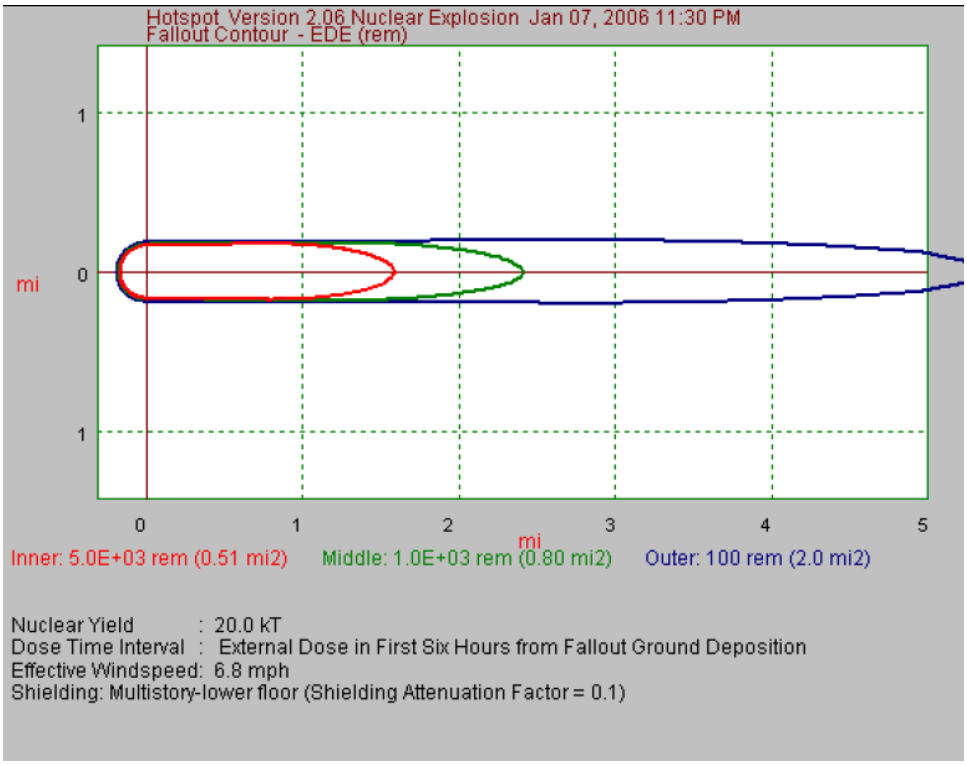
Radiation dose rates in rem during the first year post-attack, showing contours for 100 rem, 10 rem, and 100 mrem for the first year.



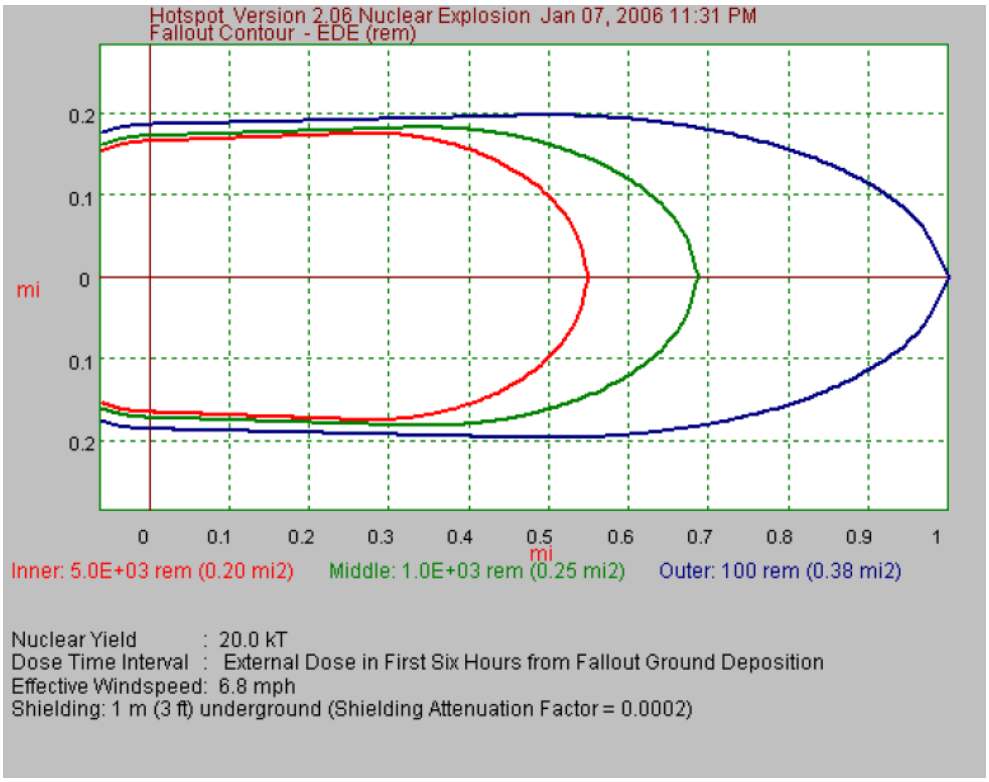
Radiation dose rates during the first year post-attack, showing contours for 5000, 1000, and 100 rem of dose.



Radiation dose rate contours showing doses of 5000, 1000, and 100 rem in the first 6 hours post-attack. Dose rates in the inner-most contour could be fatal during rescue efforts.



Radiation dose contours inside of a typical building during the first 6 hours post-attack



Radiation dose during the first 6 hours post-attack for those at least 1 meter underground.

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GLOSSARY OF TERMS

acute exposure a single exposure that results in biological harm or death; usually characterized by a brief exposure lasting no more than 7 days, as compared to longer, continuing exposure over a period of time (See also chronic exposure)

as low as reasonably achievable (ALARA) indicates that every reasonable effort must be made to maintain exposures as far below the applicable limits as practical.

alpha particle a positively charged particle made up of two neutrons and two protons emitted by certain radioactive nuclei. Alpha particles can be stopped by thin layers of light materials, such as a sheet of paper, and pose no direct or external radiation threat; however, they can pose a serious health threat if ingested or inhaled.

Americium a silvery metal; it is a man-made element whose isotopes americium-237 through -246 are all radioactive. Americium-241 is formed spontaneously by the beta decay of plutonium-241. Trace quantities of americium are widely used in smoke detectors, and as neutron sources in neutron moisture gauges.

atomic mass number the number of protons and neutrons in the nucleus of a nuclide. (The atomic mass number is not the same as the chemical atomic weight, which is the average of all the naturally occurring isotopes of an element weighted according to their relative abundances.)

atomic mass unit (AMU) 1 AMU is equal to the mass of one-twelfth of a carbon-12 atom.

Biological Effects of Ionizing Radiation (BEIR) Reports reports of the National Research Council's committee on the Biological Effects of Ionizing Radiation

Becquerel (Bq) unit used to measure radioactivity. One Becquerel is the amount of a radioactive material that will undergo one transformation in one second.

Often radioactivity is expressed in larger units like: thousands (kBq), or millions (MBq) of becquerels.

As a result of having one Becquerel being equal to one transformation per second, there are 3.7×10^{10} (37 billion) Bq in one curie.

beta particle an electron or positron emitted by certain radioactive nuclei. Beta particles can be stopped by aluminum. They can pose a serious direct or external radiation threat and can be lethal depending on the amount received. They also pose a serious internal radiation threat if inhaled or ingested.

chronic exposure exposure to a substance over a long period of time, possibly resulting in adverse health effects.

Cobalt a gray, hard, magnetic, ductile, and somewhat malleable metal, cobalt is relatively rare and generally obtained as a byproduct of other metals, such as copper. Its most common radioactive isotope is cobalt-60, which emits beta particles during radioactive decay.

Contamination the deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or people. It may also be airborne, external, or internal (inside components or people).

Controlled area An area where entry, activities, and exit are controlled to help ensure radiation protection and prevent the spread of contamination.

Criticality a term used to describe the state of a fission reaction when the number of neutrons released by fission is exactly balanced by the neutrons being absorbed and escaping. For example, reactor is said to be "critical" when it achieves a self-sustaining nuclear chain reaction, as it does when the reactor is operating.

Cumulative dose the total dose resulting from repeated exposures of ionizing radiation to an occupationally exposed worker to the same portion of the body, or to the whole body, over a period of time.

Curie a measure of radioactivity based on the observed decay rate of approximately one gram of radium. The Curie was named in honor of Pierre and Marie Curie, pioneers in the study of radiation.

One curie of radioactive material will have 37 billion atomic transformations (disintegrations) in one second.

decay, radioactive the decrease in the amount of any radioactive isotope with the passage of time due to the spontaneous emission of radiation from the atomic nuclei (either alpha or beta particles, often accompanied by gamma radiation), and consequent transformation to a different chemical form.

decay chain the series of decays that certain radioisotopes go through before reaching a stable form. For example, the decay chain that begins with Uranium-238 culminates in Lead-206, after forming intermediates such as Uranium-234, Thorium-230, Radium-226, and Radon-222. Also called the "decay series."

decay products the isotopes or elements that form and the particles and high-energy electromagnetic radiation emitted by the nuclei of radionuclides during radioactive decay. Also known as "decay chain products," "daughter products," or "progeny" (the isotopes and elements).

decontamination the reduction or removal of contaminated radioactive material from a structure, object or person. (See also decommission)

depleted uranium uranium containing less 0.7% uranium-235, the amount found natural uranium (See also enriched uranium.)

deterministic effects the results of exposure to high levels of radiation; deterministic effects are those effects that will take place when a threshold dose is exceeded, as compared to stochastic effects, which may or may not occur

examples of deterministic effects are skin burns, radiation sickness, certain teratogenic effects (e.g. mental retardation or low birth weight), and cataract formation

dirty bomb commonly refers to a device that spreads radioactive material by exploding a conventional (non-nuclear) explosive, such as dynamite. Because they do not involve the sophisticated technology required to create a nuclear explosion, dirty bombs are much simpler to make than a true nuclear bomb.

dose (radiation) denotes the quantity of radiation or energy absorbed. Dose may refer to the following:

--absorbed dose, the amount of energy deposited per unit mass

--equivalent dose, the absorbed dose adjusted for the relative biological effect of the type of radiation being measured

--committed dose, a dose that accounts for continuing exposures over long periods of time (such as 30, 50, or 70 years)

dose rate the radiation dose delivered per unit time

dosimeter a small portable instrument (such as a film badge, thermoluminescent, or pocket dosimeter) for measuring and recording the total accumulated personal dose of ionizing radiation

--dosimetry, monitoring of individuals to accurately determine their radiation dose equivalent

enriched uranium uranium in which the proportion of the isotope uranium-235 has been increased (See also depleted uranium.)

epidemiological studies studies of the distribution of disease and other health issues as related to age, sex, race, ethnicity, occupation, economic status, or other factors

exposure (radiation) a term relating to the amount of ionizing radiation that strikes a living or inanimate material. (This is a general definition. In health physics, exposure is specifically defined as a measure of ionization in air caused by x-ray or gamma radiation only.)

fallout, nuclear the slow descent of minute particles of radioactive debris in the atmosphere following a nuclear explosion.

fissile material although sometimes used as a synonym for fissionable material, this term has acquired a more restricted meaning. Namely, any material fissionable by thermal (slow) neutrons. The three primary fissile materials are uranium-233, uranium-235, and plutonium-239.

fission (fissioning) the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy. Two or three neutrons are usually released during this type of transformation. Fissioning is also referred to as 'burning.' (See also fusion.)

Fissioning that occurs without any outside cause, such as bombardment with a neutron, is called 'spontaneous fission.'

gamma rays high-energy electromagnetic radiation emitted by certain radionuclides when their nuclei transition from a higher to a lower energy state. These rays have high energy and a short wave length. All gamma rays emitted from a given isotope have the same energy, a characteristic that enables scientists to identify which gamma emitters are present in a sample. Gamma rays are very similar to x-rays

Geiger counter A radiation detection and measuring instrument. It consists of a gas-filled tube containing electrodes, between which there is an electrical voltage, but no current flowing. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of the radiation field. It is the most commonly used portable radiation detection instrument.

genetic effects hereditary effects that can be passed on through reproduction due to changes in sperm or ova.

gray (gy) a unit of measurement for absorbed dose. It relates to the amount of energy actually absorbed in a material, and is used for any type of radiation and any material. One gray is equal to one joule of energy deposited in one kg of a material. The unit gray can be used for any type of radiation, but it does not describe the biological effects of the different radiations. Absorbed dose is often expressed in terms of hundredths of a gray, or centi-grays. One gray is equivalent to 100 rads.

half-life the time in which one half of the atoms of a radioactive isotope disintegrates into another nuclear form. Half-lives vary from billionths of a billionth of a second to billions of years. Also called physical or radiological half-life.

biological half-life - the time an organism takes to eliminate one half the amount of a compound or chemical on a strictly biological basis

effective half life - incorporates both the radioactive and biological half-lives. It is used in calculating the dose received from an internal radiation source.

health physics a scientific field that focuses on radiation protection of humans and the environment. Health Physics uses physics, biology, chemistry, statistics and electronic instrumentation to help protect individuals from any damaging effects of radiation.

High radiation area any area in which a person may be exposed to radiation dose of 100 mrem in one hour at a distance of 30 cm from any surface – must be posted with the radiation symbol and “Caution, High Radiation Area” sign

Hormesis the theory that low levels of radiation are beneficial to health

internal conversion transmission of the excess energy of the nucleus to one of the orbital electrons; the electron may be ejected from the atom (ionizing radiation).

iodine a nonmetallic solid element. There are both radioactive and non-radioactive isotopes of iodine

ion (1) an atom or molecule that has too many or too few electrons, causing it to have an electrical charge, and therefore, be chemically active (2) an electron that is not associated (in orbit) with a nucleus

ionization the process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiation can cause ionization.

ionizing radiation any radiation capable of displacing electrons from atoms or molecules, thereby producing ions. Some examples are alpha, beta, gamma, and X-rays. High doses of ionizing radiation may produce severe skin or tissue damage.

irradiation exposure to radiation.

isomer (isomeric transition) A nuclide having the same number of protons and neutrons but a different energy. One isomer is usually less stable and (relatively) quickly transitions to the more stable form, releasing some energy in the process.

isotope A nuclide of an element having the same number of protons but a different number of neutrons.

linear energy transfer (LET) measures the rate of energy deposited per unit of distance a particle penetrates matter (for example, tissue). The higher the LET, the more ionizing the radiation. As a result, interactions with tissue (ionizations that damage the tissue) are more densely clustered.

linear no threshold hypothesis The theory that the number of cancers and some other effects of exposure to low levels of radiation are proportionate to the number of cancers from exposure to higher levels of radiation. By extension, there is no level of exposure that carries no risk of health effect, no matter how small the risk or exposure (no "threshold" exposure). The precise effects are uncertain because it is very difficult to measure the effects of low levels of radiation.

micron one millionth of a meter

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

Mrem millirem, one thousandth of a rem return to: [top] [previous location]

naturally occurring radioactive materials (NORM) Radioactive materials that are found in nature. Until recently, technologically enhanced naturally occurring radioactive materials (TENORM) was referred to simply as NORM. The words "technologically enhanced" were added to distinguish clearly between radionuclides as they occur naturally and radionuclides that human activity has concentrated or exposed to the environment.

Neutron a small particle possessing no electrical charge typically found within an atom's nucleus. A neutron has about the same mass as a proton.

neutron radiation Neutron radiation is energy released from an atom in the form of neutral particles called neutrons. Neutrons are part of the basic building blocks of atoms. They have no charge and are about the same mass as a proton. Due to ion-producing collisions with matter and absorption/decay processes, neutrons are a type of ionizing radiation.

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

non-stochastic effect Effects that can be related directly to the dose received. The effect is more severe with a higher does, i.e., the burn gets worse as dose increases. It typically has a threshold, below which the effect will not occur. A skin burn from radiation is a non-stochastic effect. (See also stochastic effects.)

nuclear tracers Radioisotopes that give doctors the ability to "look" inside the body and observe soft tissues and organs, in a manner similar to the way X-rays provide images of bones. A radioactive tracer is chemically attached to a compound that will concentrate naturally in an organ or tissue so that a picture can be taken.

Nucleon a proton or a neutron; a constituent of the nucleus

nucleus the central part of an atom that contains protons and neutrons. The nucleus is the heaviest part of the atom.

nuclide a general term applicable to all atomic forms of an element. Nuclides are characterized by the number of protons and neutrons in the nucleus, as well as by the amount of energy contained within the atom.

pathways the way in which people are exposed to radiation or other contaminants. The three basic pathways are inhalation (contaminants are taken into the lungs), ingestion (contaminants

are swallowed), and direct (external) exposure (contaminants cause damage from outside the body).

photon a discrete "packet" of pure electromagnetic energy. Photons have no mass and travel at the speed of light. The term "photon" was developed to describe energy when it acts like a particle (causing interactions at the molecular or atomic level), rather than a wave. Gamma and X-rays are photons.

picocurie one one-trillionth (1/1,000,000,000,000) of a curie.

plutonium a heavy, man-made, radioactive metallic element. The most important isotope is Pu-239, which has a half-life of more than 20,000 years; it can be used in reactor fuel and is the primary isotope in weapons. One kilogram is equivalent to about 22 million kilowatt-hours of heat energy. The complete detonation of a kilogram of plutonium produces an explosion equal to about 20,000 tons of chemical explosive. Plutonium is a bone-seeking radiation hazard, and can be lethal depending on the dose and exposure time.

protective action guide A protective action guide tells state and local authorities at what projected dose they should take action to protect people from exposure to unplanned releases of radioactive material into the environment.

Proton a small particle, typically found within an atom's nucleus, that possesses a positive electrical charge. The number of protons is unique for each chemical element.

quality factor (Q) The factor by which the absorbed dose (rad) is multiplied to obtain a quantity that expresses, on a common scale for all ionizing radiation, the biological damage (rem) to an exposed individual. It is used because some types of radiation, such as alpha particles, are more biologically damaging internally than other types.

rad (See Roentgen Absorbed Dose)

radiation (ionizing) energy given off as either particles or rays from the unstable nucleus of an atom

Radiation Area any area in which a person can receive a radiation dose of 5 mrem in one hour to the whole body – radiation areas must be posted with a sign that has the radiation symbol and the words “Caution – Radiation Area”

radiation sickness (syndrome) the set of symptoms that results when the whole body (or a large part of it) has received an exposure of greater than 50 rads of ionizing radiation. The earliest symptoms are nausea, fatigue, vomiting, and diarrhea. Hair loss, hemorrhaging, inflammation of the mouth and throat, and general loss of energy may follow. If the exposure has been approximately 1,000 rad or more, death may occur within two to four weeks.

radioactive contamination a deposit of radioactive material in any place where it may harm persons, equipment, or the environment.

radioactive decay The process in which an unstable (radioactive) nucleus emits radiation and changes to a more stable isotope or element. A number of different particles can be emitted by decay. The most typical are alpha or beta particles.

radioactivity the process of undergoing spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles often accompanied by gamma rays

radioassay a test to detect and determine the amount of radioactive materials present that emit ionizing radiation. It will detect transuranic nuclides, uranium, fission and activation products, naturally occurring radioactive material and medical isotopes.

radiogenic caused by exposure to ionizing radiation

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

radionuclide an unstable form of a nuclide

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

radon Radon is a naturally occurring radioactive gas found in soils, rock, and water throughout the U.S. Radon causes lung cancer, and is a threat to health because it tends to collect in homes, sometimes to very high concentrations. As a result, radon is the largest source of exposure to naturally occurring radiation.

rem (See Roentgen Equivalent Man)

risk the probability of injury, disease, or death under specific circumstances. Risk can be expressed as a value that ranges from zero (no injury or harm will occur) to one hundred percent (harm or injury will definitely occur). Risk-based standards limit the risk that releasing a contaminant to the environment may pose rather than limiting the quantity that may be released.

absolute risk, the excess risk attributed to irradiation and usually expressed as the numeric difference between irradiated and non-irradiated populations (e.g., 1 case of cancer per million people irradiated annually for each rad). Absolute risk may be given on an annual basis or lifetime basis.

relative risk, the ratio between the number of cancer cases in the irradiated population to the number of cases expected in the unexposed population. A relative risk of 1.1 indicates a 10 percent increase in cancer due to radiation, compared to the "normal" incidence.

Roentgen (R) a unit of exposure to ionizing radiation. It is an indication of the strength of the ionizing radiation.

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

Roentgen absorbed dose (rad) a basic unit of absorbed radiation dose. It is being replaced by the 'gray,' which is equivalent to 100 rad.

One rad equals the dose delivered to an object of 100 ergs of energy, per gram of material.

Roentgen Equivalent Man (rem) a unit of equivalent dose. Rem relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose.

Sievert (Sv) a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of millionths of a Sievert, or micro-Sievert. One Sievert is equivalent to 100 rem.

somatic effects of radiation effects of radiation that are limited to the exposed individual, as distinguished from genetic effects, which may also affect subsequent generations.

source or sealed source small, sealed metal cases containing radioactive materials used as references in research and industrial processes. They are often part of specialized industrial devices that measure quantities as the moisture content of soil or the density or thickness of materials. The sources are usually enclosed in a housing that prevents the escape of the radiation. Often referred to as "radioactive sources" or "sealed sources."

stable nucleus a nucleus in which the forces among its particles are balanced. See unstable nucleus as well.

stochastic effects effect that occur on a random basis with its effect being independent of the size of dose. The effect typically has no threshold and is based on probabilities, with the chances of seeing the effect increasing with dose. Cancer is a stochastic effect. (See also non-stochastic effects)

strontium a silvery, soft metal, that rapidly turns yellow in air; one of the radioactive fission materials created within a nuclear reactor during its operation. Its most common radioisotope is stronium-90, which emits beta particles during radioactive decay.

teratogenic effects non-hereditary effects from some agent that are seen in the offspring of the individual who was exposed to the agent. The agent must be encountered during the gestation period.

thorium a naturally occurring radioactive metal found at very low levels in soil, rocks, water, plants and animals. The most common naturally occurring forms of thorium are thorium-232, thorium-230 or thorium-228.

Transuranic elements with atomic numbers higher than uranium (92). For example, plutonium and americium are transuranics.

Tritium Tritium (chemical symbol H-3) is a radioactive isotope of the element hydrogen (chemical symbol H).

unstable nucleus an atom is unstable (radioactive) if the forces among the particles that make up the nucleus are unbalanced, that is tosay, if the nucleus has an excess of internal energy. See also stable nucleus.

uranium a naturally occurring radioactive element whose principal isotopes are Uranium-238 and Uranium-235. Natural uranium is a hard silvery-white shiny metallic ore that contains a minute amount of Uranium-234.

UV ultraviolet light; that portion of the electromagnetic spectrum that has a higher frequency and shorter wavelength than violet light; UV has three recognized wavelength bands, UVA (320-400 nm), UVB (290-320 nm), and UVC (<290 nm)

Very high radiation area any area in which a person can receive a radiation dose of 500 mrem to the whole body in one hour at a distance of 30 cm from any surface – very high radiation areas must be posted with a sign that has the radiation symbol and says “Grave Danger – Very High Radiation Area”

whole body exposure An exposure of the body to radiation, in which the entire body, rather than an isolated part, is irradiated.

x-rays high-energy electromagnetic radiation emitted by atoms when electrons fall from a higher energy shell to a lower energy shell. These rays have high energy and a short wave length. X-rays are very similar to gamma rays.

Radiological terrorism – general information for the public

What is radiological terrorism?
Terrorists may decide to take advantage of our fear of radiation and radioactivity to cause disruption and fear in New York City. They may do this by spreading radioactive materials in public places, by setting off a "dirty bomb" to spread radioactive materials in an explosion, by putting radioactive materials in food or water, or by placing a radioactive source in a public place to try to make people ill from radiation sickness.

What are the risks from radiological terrorism?
In general, radiological terrorism is very unlikely to hurt many people because the radiation levels from even a concentrated source of radioactivity dissipates rapidly with distance, and because ingesting or inhaling small amounts of radioactivity, while not desired, will not cause high levels of radiation dose to people. There are some circumstances under which a small number of people who are in close proximity to a source of radiation for many minutes may be injured, but there are only a few such scenarios, and none of them are likely to cause a large number of injuries or injuries to people who are more than about 20 feet away.

What is the difference between radiation and contamination?
Radiation is given off by radioactive materials and it can be detected at a distance from the source of radiation. Radiation is either rays (such as gamma rays) or particles (such as alpha or beta particles). Radioactive materials such as uranium or cobalt-60 are inherently radioactive – they give off radiation all the time.

On the other hand, someone may spill radioactive materials onto something that is not normally radioactive. This is contamination. For example, if you spill uranium onto the street and then perform a radiation survey, the street will look as though it's radioactive – you'll be able to "see" the radioactivity with a radiation meter. The street is not radioactive; it's the uranium that's making it look that way, and cleaning up the contamination will make the radioactivity go away.

What radiation level is dangerous?
We are all exposed to low levels of radiation from nature all the time. This low level of radiation exposure is safe because it's part of our environment. But we can be exposed to much higher levels of radiation without becoming ill – this happens all the time when the doctor takes x-rays or CT scans. Radiation levels are measured in units called "rem" – 1 rem is the same amount of radiation that we receive in about 3 years from nature. Radiation workers are allowed to receive 5 rem in a year, and medical studies have shown that this is a safe level of exposure. In fact, it takes an exposure of about 100 rem in a short time to cause a person to develop radiation sickness, and these people will recover from the exposure.

Radiation can also cause cancer, but it's not very efficient at doing so. Normally, about 1 person in 4 will get cancer, and about 1 person in 6 dies of cancer in the US. If a large group of people are exposed to the relatively high dose of 100 rem each (enough to cause mild radiation sickness), then an additional 1-2% of the population may die of cancer. This is about the same risk as we face from driving in the US.

Radiological terrorism – general information for the public

Radiological terrorism – general information for the public

Is a high level of contamination dangerous?
Not necessarily. A high level of contamination means that you will get a lot of "counts" when you perform a radiological survey. But a lot of counts in the form of skin contamination does not mean there is a lot of danger. For example, if you throw a handful of sand at a person, they may feel thousands of grains of sand hitting them, but these thousands of "counts" of sand will not hurt them (as long as you don't throw it at their eyes). By the same token, even relatively high levels of radioactive contamination are not necessarily dangerous as long as the contamination does not enter the body because the radiation dose is fairly low.

So what is the highest risk from radiological terrorism?
The risks depend on the type of attack. If you are standing right next to a large gamma radiation source (such as Co-60 or Cs-137), you are at a relatively high risk of developing radiation sickness because of the high radiation levels. On the other hand, standing on a site that's contaminated with Co-60, even at fairly high levels of contamination, is not very dangerous because the radiation levels are probably not going to be very high. Driving away from a dirty bomb attack in a panic is likely to be dangerous because driving is always somewhat risky (especially when the roads are filled with a lot of other scared people). Here are some of the risks from a radiological attack:

Activity	Risk
Driving from the scene	High
Crossing a contaminated site	Low to moderate
Inhaling radioactivity	High (if it's alpha activity) Low to moderate (for beta or gamma activity)
Being involved in a dirty bomb attack	High from the explosion itself Low to moderate from the radioactivity
Exposure to 100 rem of radiation	Low to moderate (slight increase in cancer risk in the long run, mild radiation sickness right away)
Eating food with low levels of radioactive contamination	Low to moderate, depending on the type of radioactivity (alpha, beta, or gamma)
Drinking water with low levels of radioactive contamination	Low to moderate, depending on the type of radioactivity (alpha, beta, or gamma)

What actions can I take to make me and my family safer after a radiological attack?
1. Stay off the roads – walk away, don't drive
2. If you can't see or hear an explosion, you are probably not at any risk at all from the attack
3. Go indoors and shut any open doors and windows and place furnace or air conditioning in recirculating mode.
4. Shower and change clothes if you can
5. If you have a home vegetable garden you should not eat your veggies if you're downwind of the attack
6. Listen to TV or radio to find out what's happening, where the attack took place, and what they recommend people in your area should do

Radiological terrorism – general information for the public

Please explain the information in the boxes on the fact sheets!

Sr-90

Half-life = 29 years
beta particle = 546 keV
x-ray radiation
From Y-90 daughter
beta particle = 2293 keV
gamma rays = 203, 480 keV

Co-60

Half-life = 5.27 yrs
gamma ray = 1100, 1330 keV
Dose rate = 1.332 rad/hr at 1 yard from 1 Curie

- The top line is the "name" of the radioactive material. Sr stands for strontium and Co means cobalt. The numbers (90 and 60) tell how many neutrons and protons are in the nuclei (the center part) of the atoms.
- The half-life is the rate at which the radioactive materials decay to stable atoms. The amount of radioactivity drops by a factor of 2 after each half-life. A longer half-life means that the radioactive material decays (goes away) more slowly, so it's around longer.
- keV is a measure the amount of energy in the radiation that is emitted. keV stands for "kilo electron volt", a very small amount of energy. As the energy increases, the radiation is more penetrating and can cause more damage
- The radiation dose rate (only from gamma-emitting isotopes) tells how much radiation dose you will measure at a distance of about a yard from a radioactive source of a given strength. A higher number means that the radioactive material is more dangerous.
- In the case of Sr-90, the isotope turns into another radioactive atom when it decays. The Y-90 "daughter" isotope gives off both gamma and beta radiation, which must be included to be complete.

Radiological fact sheet: Radiation units and terminology

Radiation units

Curie (Ci) A unit of radioactivity that measures the rate at which radiation is emitted from radioactive materials. Radiation levels and risk are related to the number of Curies present. In general, sources that are less than a few hundred Curies will not emit dangerous levels of radiation. The international unit is the Becquerel (abbreviated Bq); sources that are less than a few billion Bq (a few GBq) do not emit dangerous amounts of radiation.

Rad A unit of radiation dose that measures the amount of energy from radiation you have absorbed. In general, a dose of about 100 rad will begin to cause radiation sickness and doses of several hundred rads may be lethal. The international unit is the Gray (Gy); 1 Gy is equal to 100 rad.

Rem A unit of radiation dose that accounts for the different biological effects of various kinds of radiation. Radiation workers are limited to 5 rem annually from normal work and are allowed to receive up to 25 rem in emergency situations. To save lives, there are no limits given, but some organizations recommend 50 rem. The international unit is the Sievert (Sv); 1 Sv is equal to 100 rem.

Terminology

Radiation Radiation is energy that is given off by unstable atoms. The energy comes out in the form of gamma rays, alpha particles, and beta particles. Radiation is emitted from radioactive materials – it is one of their properties, along with color, size, and weight.

Contamination
The presence of radioactivity in an area or on something that is not normally radioactive. In a dirty bomb attack, radioactive contamination would be spread over streets, sidewalks, or buildings that would need to be cleaned up. It is possible to have high levels of contamination that do not produce high levels of radiation because contamination measures only the amount of radioactivity present and not the damage caused by that radiation. Contamination is measured in units of counts per minute (cpm) using a Geiger counter or similar instrument.

Alpha Alpha radiation consists of particles (on an atomic level) that are emitted by heavy atoms such as uranium, radium, or lead. Alpha radiation is not a hazard unless it is inhaled, ingested, or enters the body through open cuts or scrapes. However, if it does enter the body, it is the most damaging form of radiation. If you are working in the presence of alpha contamination, you must take precautions to avoid inhaling or ingesting any alpha radioactivity, and any open wounds should be bandaged if at all possible.

Radiological fact sheet: Radiation units and terminology

Radiological fact sheet: Radiation units and terminology

Beta Beta radiation consists of particles, although they are smaller than alpha particles. Any element can emit beta radiation. Beta radiation will only penetrate up to a half inch in human tissue, so it will not expose internal organs unless it is ingested or inhaled. Some beta-emitting radioactive materials can be absorbed through the skin; beta radioactivity can also enter the body by ingestion, inhalation, or through open wounds. Beta radiation is much less damaging than alpha radiation, but drops of beta radioactivity can cause localized skin burns under some circumstances. If you are working in the presence of beta radiation, you should take precautions to avoid ingesting or inhaling radioactivity, and you should wear protective clothing (see the PPE fact sheet) to avoid having beta contamination on your bare skin.

Gamma Gamma radiation consists of rays that are similar to x-rays or light rays. Any element can emit gamma radiation. Gamma rays will penetrate through the entire body, just like x-rays, so external gamma radiation will cause radiation dose to internal organs. However, gamma radiation is much less damaging than alpha radiation. Some gamma-emitting isotopes are absorbed through the skin, and it is also possible for gamma-emitting radioactivity to be ingested or inhaled. If you are working in the presence of gamma radiation, you should take precautions to avoid inhaling or ingesting radioactivity and you should wear protective clothing to avoid having gamma contamination on your skin.

Half-life The amount of time it takes for one half of an amount of radioactivity to decay away. For example, the half-life of I-131 is 8 days, so a 1 Ci I-131 source will have only 0.5 Ci after 8 days, 0.25 Ci after 16 days, and 0.125 Ci after 24 days. After each half-life, the amount of radioactivity remaining drops by a further factor of 2.

Radiological fact sheet: Radiation units and terminology

Radiation Fact Sheet: Alpha-emitting radioactivity
Americium-241, Californium-252, Radium-226

What is alpha radiation?
Where does alpha radiation come from?
How dangerous is alpha radiation?
How does alpha radiation affect the body?
Just the facts about these isotopes!
What does an alpha radiation source look like?
How could a terrorist use alpha radiation?
How can I protect myself from a terrorist attack with alpha radiation?

What is alpha radiation?

Alpha radiation is a form of particulate radiation that is emitted by heavy atoms such as uranium. Alpha radiation can travel only a few inches in air, and cannot penetrate our skin to cause radiation exposure to our internal organs. Alpha radiation is used in smoke detectors, static eliminators, and in many gauges used in the mining and drilling industries. Many radioactive sources use alpha-emitting radioactivity to generate neutrons, and these neutrons may be hazardous under some circumstances.

Where does alpha radiation come from?

Alpha radiation is emitted by unstable (radioactive) atoms such as uranium, radon, radium, thorium, and plutonium. Some of these – uranium, radon, radium, and thorium – are found in nature while others – plutonium, americium, californium – are created in nuclear reactors or in linear accelerators

How dangerous is alpha radiation?

Alpha radiation cannot penetrate our skin cells, so external alpha radiation (for example, powder on the skin) is not dangerous as long as it remains outside our bodies. However, alpha radiation is very damaging to living cells, and any alpha radiation that enters the body can cause a high level of damage. The most serious route of exposure is inhalation; if large amounts of alpha radioactivity are inhaled, they can cause problems to our lungs. Alpha radioactivity on our food is also a concern, although this route of exposure is not as dangerous as inhalation. You should always take care to minimize the amount of alpha radioactivity that can enter the body through the lungs, the mouth, or through open cuts or scrapes. In addition, some alpha radioactivity may be used to generate potentially hazardous levels of neutron radiation.

- High-activity alpha sources may be dangerous due to neutrons produced by these sources.
- Alpha sources should not be held in the hand at any time.
- Inhaled alpha radioactivity may be very dangerous
- Ingested alpha radioactivity may be moderately dangerous

Radiation Fact Sheet: Alpha-emitting radioactivity
Americium-241, Californium-252, Radium-226

Radiation Fact Sheet: Alpha-emitting radioactivity
Americium-241, Californium-252, Radium-226

Just the facts about these isotopes!

Am-241

Half-life = 433 yrs
alpha particle = 5.5 MeV
gamma ray = 60 keV
neutron emissions from some sources
Dose rate = 0.32 rad/hr at 1 yard from 1 Curie

- Americium-241 (abbreviated Am-241 or ^{241}Am) has a half-life of about 433 years, so an area contaminated with Am-241 will take many centuries to wait for the radioactivity to naturally decrease through radioactive decay.
- Am-241 emits a single gamma ray with a low energy and high-energy alpha particles. Neutrons are also emitted from Am neutron sources
- When in the body (if it is swallowed or inhaled), Am-241 goes to the bones and the liver.
- Inhaled Am-241 can be moderately to very dangerous
- Am-241 radioactive sources are usually only moderately radioactive.

Cf-252

Half-life = 2.65 years
alpha particle = 6.1 MeV
neutrons are also emitted
Dose rate = not applicable because no gammas are emitted

- Californium-252 (abbreviated Cf-252 or ^{252}Cf) has a half-life of slightly over 2 ½ years, so an area contaminated with Cf-252 will take several years to wait for the radioactivity to naturally decrease through radioactive decay.
- Cf-252 emits both high-energy alpha particles and neutrons
- When inhaled Cf-252 gives the highest radiation dose to the bones, the liver, and the lungs; and dose is highest to the bones if it is swallowed.
- The radiation dose from a Cf-252 source is higher than with many other alpha-emitters because of the neutron radiation, but it is lower than for most gamma emitting sources.

Ra-226

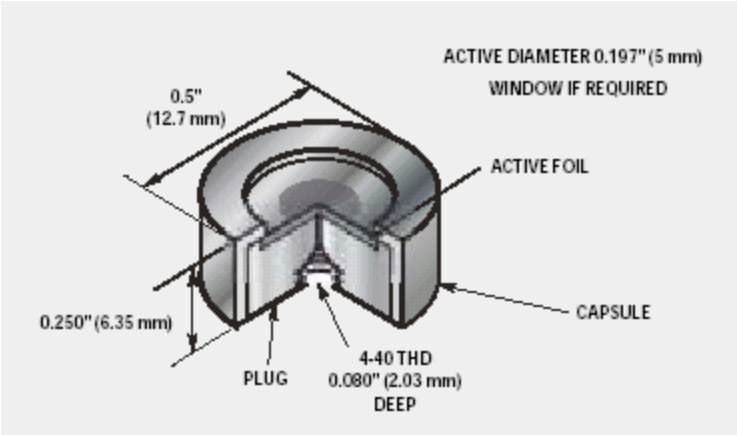
Half-life = 1600 years
alpha particle =
gamma ray = 185 keV
Dose rate = rad/hr at 1 yard from 1 Curie

- Radium-226 (abbreviated Ra-226 or ^{226}Ra) has a half-life of about 1600 years, so an area contaminated with Ra-226 will not experience any noticeable reduction in contamination levels over a human lifetime.
- Ra-226 emits a low-energy gamma ray and a moderate-energy alpha particle.
- If a person inhales Ra-226 the lungs receive the highest dose of radiation and, if it is swallowed, the highest radiation dose is to the bones and intestines.
- Radiation dose to the body from inhaling or swallowing Ra-226 is less than from the same amount of an alpha emitting isotope, but is higher than from low-energy beta emitters.
- Ra-226 sources may be moderately radioactive, and they are a moderate to high risk from leaking radioactivity

Radiation Fact Sheet: Alpha-emitting radioactivity
Americium-241, Californium-252, Radium-226

Radiation Fact Sheet: Alpha-emitting radioactivity Americium-241, Californium-252, Radium-226

What does an alpha radiation source look like?



In general, alpha radiation sources are encased in silvery metal such as stainless steel. Small sources, such as those used to perform radiation instrument calibrations, may look like small disks or miniature hockey pucks up to an inch in diameter. Sources used in smoke detectors are usually thin (sometimes gold-colored) foils that may be only a fraction of an inch on a side. Some old radium cancer therapy sources may be about the size of a mechanical pencil lead, and sources that are used in industry may be small cylinders up to an inch in diameter and 1-2 inches long.

How could a terrorist use alpha radiation?

- Terrorists may make a radiological dispersal device (RDD, or "dirty" bomb") by making a fine powder of the source, using explosives to spread the powder to contaminate large areas. In this case, the radiation and contamination levels are not likely to be dangerously high, but the health risk from inhaling alpha radioactivity can be moderate to high.
- Terrorists may use radioactive powder to try to contaminate the food or water supply. If put into water, the radioactivity will probably be filtered out by the water treatment plants. Alpha radioactivity put onto food will probably cause a moderate risk, although washing food thoroughly prior to eating will reduce this risk significantly.
- Terrorists may spray alpha radioactivity into the air or into ventilation systems. The risk from inhaled alpha radioactivity is moderate to high.

How can I protect myself from a terrorist attack with alpha radiation?

- In the event of an outside attack using airborne alpha radioactivity, you should try to get out of the plume by going indoors.
- If you are indoors and the building you are in experiences high levels of airborne alpha radioactivity you should breathe through a folded handkerchief and follow instructions to exit the building in an orderly manner
- In the event of an RDD attack, you should go indoors and shut open doors and windows. Listen to the TV or radio for further instructions.
- **DO NOT** attempt to drive away from the site of a radiological attack.
- If you are upwind of the attack, no further actions are necessary because the radioactivity will travel away from you.
- If you are downwind of the attack, you should change clothes and take a shower (or at least wash your hands and face) after going indoors.
- If you are outdoors and can see or hear the explosion, you should fold a handkerchief or other piece of cloth several times and breathe through it until you are indoors.

Radiation Fact Sheet: Alpha-emitting radioactivity Americium-241, Californium-252, Radium-226

Radiation Fact Sheet: Beta-emitting radioactivity
Tritium, Phosphorus-32, Sulfur-35

What is beta radiation?
Where does beta radiation come from?
How dangerous is beta radiation?
How does beta radiation affect the body?
Just the facts about these three sources of beta radiation!
What does a beta radiation source look like?
How could a terrorist use beta radiation?
How can I protect myself from a terrorist attack with beta radiation?

What is beta radiation?

Beta radiation is a form of particulate radiation that consists of electrons that are emitted from unstable (radioactive) atoms. Beta radiation travels at very high speeds, it can penetrate up to about a half inch in the human body, and is best shielded using plastic (up to a half inch thick). Tritium, phosphorus-32, and sulfur-35 are used in biological and medical research, and phosphorus-32 is used in some types of cancer therapy. Tritium is used in some self-luminous products (such as exit signs) and is also used in thermonuclear weapons.

Where does beta radiation come from?

Beta radiation is emitted from the nucleus of unstable (radioactive) atoms, such as tritium, phosphorus-32, and sulfur-35. These are produced in industrial accelerators or in nuclear reactors and made into sources.

How dangerous is beta radiation?

Beta radiation can penetrate only a half inch into the body, so it does not pose an external radiation hazard. However, high levels of beta radiation to parts of the body (such as the hand, if you try to pick up a beta source) can cause harm. The beta-emitting radionuclides discussed here do not pose a serious risk if ingested or inhaled in small quantities, although this should be avoided when possible.

- Very high-activity beta radiation sources can be very dangerous at short distances (less than 10-20 feet).
- Low-activity beta radiation sources are not dangerous unless they are held in the bare hand.
- Ingested or inhaled beta radioactivity is slightly to moderately dangerous
- Beta radioactivity on bare skin can cause localized skin burns in an hour or less, depending on the amount of radioactivity present

Radiation Fact Sheet: Beta-emitting radioactivity
Tritium, Phosphorus-32, Sulfur-35

Radiation Fact Sheet: Beta-emitting radioactivity
Tritium, Phosphorus-32, Sulfur-35

Just the facts about these three sources of beta radiation!

Tritium (H-3)

Half-life = 12 ¼ yrs
beta particle = 18 keV

radiation penetrates ~ 1 mm in human tissue and ~ 1 cm in air

- Tritium (abbreviated H-3 or ^{3}H) has a half-life of about 12 ¼ years, so an area contaminated with tritium will take many years to wait for the radioactivity to naturally decrease through radioactive decay.
- Tritium emits a single beta particle with a very low energy.
- When in the body (if it is swallowed or inhaled), tritium distributes fairly evenly through the body, and the radiation dose from a given amount of tritium is lower than from virtually any other nuclide.
- Tritium sources are not dangerous provided that large quantities of tritium are not ingested or inhaled.

P-32

Half-life = 14.3 days
beta particle = 1.71 MeV

radiation penetrates ~ ½" in human tissue and up to 20 feet in air

- Phosphorus-32 (abbreviated P-32 or ^{32}P) has a half-life of about 2 weeks, so an area contaminated with P-32 will see a significant reduction in contamination levels in just a few weeks due to radioactive decay.
- P-32 emits a single beta particle with a high energy.
- When inhaled P-32 gives the highest radiation dose to the lungs, and dose is highest to the bones and intestines if it is swallowed.
- The radiation dose from a given amount of P-32 is lower than from alpha-emitting isotopes.
- P-32 sources pose moderate risk if spilled on the skin, ingested, or inhaled; and low risk if the sources remain intact

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S-35

Half-life = 89 days
beta particle = 168 keV

radiation penetrates less than ¼" in human tissue and up to a few feet in air

- Sulfur-35 (abbreviated S-35 or ^{35}S) has a half-life of about 3 months, so an area contaminated with S-35 will show a large drop in radioactivity levels in just a year (contamination levels will drop by a factor of about 10 in one year).
- S-35 emits a single beta particle with a low energy.
- If a person inhales S-35 the lungs receive the highest dose of radiation and, if it is swallowed, the highest radiation dose is to the stomach and intestines.
- Radiation dose to the body from inhaling or swallowing S-35 is less than from the same amount of most other types of radioactive materials.
- S-35 sources are usually not dangerous, although people should take care to avoid having S-35 directly contact the skin

Radiation Fact Sheet: Beta-emitting radioactivity
Tritium, Phosphorus-32, Sulfur-35

Radiation Fact Sheet: Beta-emitting radioactivity
Tritium, Phosphorus-32, Sulfur-35

What does a beta radiation source look like?

In general, these beta-emitting radioactive materials are used in research and they are usually stored as clear liquids in small plastic bottles and vials These bottles are normally made of clear glass or plastic and have a label with information about the radioactive materials and with the radiation symbol.

How could a terrorist use beta radiation?

- Terrorists may make a radiological dispersal device (RDD, or "dirty" bomb") by using explosives to spread radioactive liquid to contaminate large areas. In this case, the radiation and contamination levels are not likely to be dangerously high.
- Terrorists may spread radioactive liquid in small areas, such as public buildings or streets. In this case, there is very little risk from beta-emitting radioactivity
- Radiation levels from one of these beta-emitting sources will not be high enough to cause any risk to people in the area.
- Terrorists may use radioactive liquids to try to contaminate the food or water supply. If put into water, the radioactivity will probably be filtered out by the water treatment plants. Beta radioactivity put onto food will probably not cause a great risk, although washing food thoroughly prior to eating will reduce this risk further.

How can I protect myself from a terrorist attack with beta radiation?

- In the event of an RDD attack, you should ***go indoors*** and shut open doors and windows. Listen to the TV or radio for further instructions.
- **DO NOT** attempt to drive away from the site of a radiological attack.
- If you are upwind of the attack, no further actions are necessary because the radioactivity will travel away from you.
- If you are downwind of the attack, you should ***change clothes and take a shower*** (or at least wash your hands and face) after going indoors.
- ***If you are outdoors and can see or hear the explosion***, you should fold a handkerchief or other piece of cloth several times and breathe through it until you are indoors.
- If you may have radioactivity on your hands or face, or if you are in an area that may be contaminated with radioactivity, ***you should not eat, drink, smoke, apply cosmetics, chew tobacco,*** or take other actions that could lead to accidentally ingesting radioactive materials

Radiation Fact Sheet: Beta-emitting radioactivity
Tritium, Phosphorus-32, Sulfur-35

Radiation Fact Sheet: Gamma-emitting radioactivity Cesium-137, Cobalt-60, Iridium-192

What is gamma radiation?
Where does gamma radiation come from?
How dangerous is gamma radiation?
How does gamma radiation affect the body?
Just the facts about these gamma radiation sources!
What does a gamma radiation source look like?
How could a terrorist use gamma radiation?
How can I protect myself from a terrorist attack with gamma radiation?

What is gamma radiation?

Gamma radiation is a form of electromagnetic radiation that is similar to x-rays. Gamma radiation travels at the speed of light, it can penetrate through the whole body, and is best shielded using lead or other very dense materials. Gamma radiation is used to help sterilize surgical equipment, to help control some industrial processes, for some kinds of cancer therapy, for non-destructive testing, and more.

Where does gamma radiation come from?

Gamma radiation is emitted from the nucleus of unstable (radioactive) atoms, such as Cobalt-60, Cesium-137, and Iridium-192. These are produced in nuclear reactors or in linear accelerators, and the radioactive atoms are made into sources such as those described above.

How dangerous is gamma radiation?

High levels of gamma radiation exposure to the whole body can be dangerous, and high levels of gamma radiation to parts of the body (such as the hand, if you try to pick up a gamma source) can cause serious damage. Gamma radiation is very penetrating, so it can cause radiation exposure even to internal organs, and it can cause exposure even at a distance from the source. However, each gamma ray photon only causes a small level of damage as it passes through the body. Although gamma radiation causes less damage to the cells of our body than alpha radiation does, gamma radiation sources can be much more potent than alpha radiation sources.

- Very high-activity gamma radiation sources can be very dangerous at short distances (less than 10-20 feet).
- Low-activity gamma radiation sources are not dangerous unless they are held in the bare hand.
- Ingested or inhaled gamma radioactivity is moderately dangerous

Radiation Fact Sheet: Gamma-emitting radioactivity Cesium-137, Cobalt-60, Iridium-192

Radiation Fact Sheet: Gamma-emitting radioactivity
Cesium-137, Cobalt-60, Iridium-192

Just the facts about these gamma radiation sources!

Cs-137

Half-life = 30 yrs
gamma ray = 662 keV
Dose rate = 0.332 rad/hr
at 1 yard from 1 Curie

- Cesium-137 (abbreviated Cs-137 or ^{137}Cs) has a half-life of about 30 years, so an area contaminated with Cs-137 will take many years to wait for the radioactivity to naturally decrease through radioactive decay.
- Cs-137 emits a single gamma ray with a moderately high energy.
- When in the body (if it is swallowed or inhaled), Cs-137 distributes fairly evenly through the body, and the radiation dose from a given amount of Cs-137 is lower than from alpha-emitting isotopes, but higher than low-energy beta emitters.
- Cs-137 sources can range from extremely safe to dangerously radioactive.

Co-60

Half-life = 5.27 yrs
gamma ray = 1100, 1330 keV
Dose rate = 1.332 rad/hr
at 1 yard from 1 Curie

- Cobalt-60 (abbreviated Co-60 or ^{60}Co) has a half-life of about 5¼ years, so an area contaminated with Co-60 will take several years to wait for the radioactivity to naturally decrease through radioactive decay.
- Co-60 emits dual gamma rays with a high energy.
- When inhaled Co-60 gives the highest radiation dose to the lungs, and dose is highest to the intestines if it is swallowed.
- The radiation dose from a given amount of Cs-137 is lower than from alpha-emitting isotopes, but higher than low-energy beta emitters.
- Co-60 sources can range from extremely safe to dangerously radioactive.

Ir-192

Half-life = 74 days
gamma = 317, 468 keV
Dose rate = 0.592 rad/hr
at 1 yard from 1 Curie

- Iridium-192 (abbreviated Ir-192 or ^{192}Ir) has a half-life of about 2½ months (74 days), so an area contaminated with Ir-192 will show a significant drop in radioactivity levels in just a year (radiation and contamination levels will drop by a factor of over 30 in one year).
- Ir-192 emits a several gamma rays with moderate energies.
- If a person inhales Ir-192 the lungs receive the highest dose of radiation and, if it is swallowed, the highest radiation dose is to the intestines.
- Radiation dose to the body from inhaling or swallowing Ir-192 is less than from the same amount of an alpha emitting isotope, but is higher than from low-energy beta emitters.
- Ir-192 sources usually range from somewhat hazardous to dangerously radioactive

Radiation Fact Sheet: Gamma-emitting radioactivity
Cesium-137, Cobalt-60, Iridium-192

Radiation Fact Sheet: Gamma-emitting radioactivity Cesium-137, Cobalt-60, Iridium-192

What does a gamma radiation source look like?

In general, gamma radiation sources are encased in silvery metal such as stainless steel. Small sources, such as those used to perform radiation instrument calibrations, may look like small disks or miniature hockey pucks up to an inch in diameter. Sources used for cancer therapy may be even smaller – some are thinner than a mechanical pencil lead and are less than 1/8 inch long. Other cancer therapy sources may be up to 2 inches in diameter and 1-2 inches long. Gamma radiation sources used for industrial purposes or radiography are usually an inch or so long and up to a half inch in diameter, which sources used for sterilization may be the size of a pencil. Cs-137 sources may contain a fine, blue powder if they are opened up; this powder is highly radioactive and should not be handled.



An example of a gamma radiation source

How could a terrorist use gamma radiation?

- Terrorists may make a radiological dispersal device (RDD, or "dirty" bomb") by making a fine powder of the source, using explosives to spread the powder to contaminate large areas. In this case, the radiation and contamination levels are not likely to be dangerously high.
- Terrorists may use an intact source to irradiate people to try to cause radiation sickness. In this case, there will be little or no contamination, but radiation levels may be dangerously high to people within 10 or 20 feet of the source.
- Terrorists may use radioactive powder to try to contaminate the food or water supply. If put into water, the radioactivity will probably be filtered out by the water treatment plants. Gamma radioactivity put onto food will probably not cause a great risk, although washing food thoroughly prior to eating will reduce this risk further.

How can I protect myself from a terrorist attack with gamma radiation?

- In the event of an RDD attack, you should go indoors and shut open doors and windows. Listen to the TV or radio for further instructions.
- **DO NOT** attempt to drive away from the site of a radiological attack.
- If you are upwind of the attack, no further actions are necessary because the radioactivity will travel away from you.
- If you are downwind of the attack, you should change clothes and take a shower (or at least wash your hands and face) after going indoors.
- If you are outdoors and can see or hear the explosion, you should fold a handkerchief or other piece of cloth several times and breathe through it until you are indoors.
- If you are exposed to radiation from a radioactive source, move to a distance of at least 100 feet and wait for further instructions. If you believe you were exposed for a prolonged time (at least 15 minutes at close range), inform emergency responders and seek medical attention.
- If you are in the vicinity of a radioactive source, try to stand behind some shielding such as a vehicle or a wall.

Radiation Fact Sheet: Gamma-emitting radioactivity Cesium-137, Cobalt-60, Iridium-192

Radiation Fact Sheet: Iodine-131

What is Iodine-131?
Where does Iodine-131 come from?
How dangerous is Iodine-131?
How does Iodine-131 affect the body?
What does an Iodine-131 source look like?
How could a terrorist use Iodine-131?
How can I protect myself from a terrorist attack with Iodine-131?

What is Iodine-131?

Iodine-131 is a radioactive form of the element iodine. Iodine-131 emits gamma rays, which travel many feet in air and beta particles, which travel only a short distance. Iodine-131 is only used for medical diagnoses and cancer therapy.

Where does Iodine-131 come from?

Iodine-131 is manufactured by radiopharmaceutical manufacturers in nuclear reactors and in particle accelerators. After it is produced, it is shipped to local radio-pharmacies, who measure it into doses that are sent to hospitals for individual patients. The hospitals then administer the Iodine-131 to their patients to diagnose or treat thyroid disease.

How dangerous is Iodine-131?

Iodine-131 is easily absorbed through the skin, lungs, and digestive tract. Once in the body, the only organ that absorbs Iodine-131 is the thyroid gland, and the thyroid can receive a very high dose of radiation from any Iodine-131 that enters the body. For this reason, Iodine-131 may be dangerous to the thyroid and can cause thyroid cancer, but it does not affect the rest of the body.

- High-activity Iodine-131sources may emit moderately high levels of radiation
- Iodine-131 that is inhaled, ingested, or spilled on the skin can give a high radiation dose to the thyroid
- Syringes or vials containing Iodine-131 should not be held in the hand at any time.

What are the properties of Iodine-131?

I-131

Half-life = 8 days
gamma ray = 365 keV
beta particle = 606 keV
Dose rate = 0.013 rad/hr at 1 yard from 1 Curie

- Iodine-131 (abbreviated I-131 or ^{131}I) has a half-life of about 8 days, so an area contaminated with I-131 will experience very significant decay in just a few weeks.
- I-131 emits a single gamma ray with a moderate energy and medium-energy beta particles.
- When in the body (if it is swallowed or inhaled), I-131 goes to the thyroid gland.
- Inhaled or ingested I-131 can be moderately to very dangerous because the thyroid is sensitive to radiation
- Syringes or small bottles of I-131 may emit moderately high levels of radiation

Radiation Fact Sheet: Iodine-131

Radiation Fact Sheet: Iodine-131

What does an I-131 source look like?

When prepared for medical use, Iodine-131 is almost always found in either vials (such as the one pictured at the right) or in syringes. In such cases, the vial, syringe, or the lead shield should clearly say that it contains radioactive Iodine-131. The iodine itself is usually present as a clear liquid inside the vial or syringe. Iodine 1-131 may also be present in the fallout from a nuclear weapon, in which case it is not readily identified by sight.



An example of an I-131 vial and its lead shield

How could a terrorist use I-131?

- Terrorists may make a radiological dispersal device (RDD, or "dirty" bomb") by adding liquid I-131 solution to explosives; the explosion will then spread the I-131 to contaminate large areas. In this case, the radiation and contamination levels are not likely to be dangerously high, but the health risk from inhaling or ingesting iodine-131can be moderate to high.
- Terrorists may use radioactive I-131 to try to contaminate the food or water supply. If put into water, the radioactivity will probably be filtered out by the water treatment plants. I-131 put onto food will probably cause a moderate to high risk depending on the amount that is ingested, although washing food thoroughly prior to eating will reduce this risk significantly. However, if food contaminated with I-131 is handled with bare hands, some iodine may be absorbed directly into the skin

How can I protect myself from a terrorist attack with I-131?

- **If authorities have confirmed the presence of I-131** AND if you are downwind of the attack and in the plume (as shown on TV) children and young adults may be given potassium iodide (KI) tablets to reduce radiation dose to the thyroid. It is generally not necessary to give KI to adults over the age of 40
- In the event of an RDD attack, you should go indoors and shut open doors and windows. Listen to the TV or radio for further instructions.
- **DO NOT** attempt to drive away from the site of a radiological attack.
- If you are upwind of the attack, no further actions are necessary because the radioactivity will travel away from you.
- If you are downwind of the attack, you should change clothes and take a shower (or at least wash your hands and face) after going indoors.
- If you are outdoors and can see or hear the explosion, you should fold a handkerchief or other piece of cloth several times and breathe through it until you are indoors.
- If you have a home garden and if you are downwind of the attack, you should wash the fruits or vegetables from your garden before you eat them

Radiation Fact Sheet: Iodine-131

Radiation Fact Sheet: Strontium-90

What is Strontium-90?
Where does Strontium-90 come from?
How dangerous is Strontium-90?
Just the facts about Sr-90!
What does a Strontium-90 source look like?
How could a terrorist use Strontium-90?
How can I protect myself from a terrorist attack with Strontium-90?

What is Strontium-90?

Strontium-90 is a radioactive form of the element strontium. Strontium-90 emits high-energy beta particles, which travel several feet in air, but only a half inch in the body. Strontium-90 is used in some industrial gauges and in some medical applications. The heat it generates during radioactive decay is also used to generate power for some spacecraft, weather stations, lighthouses, and other remote applications.

Where does Strontium-90 come from?

Strontium-90 is manufactured primarily in nuclear reactors as a product of nuclear fission. There is also some in the environment from the era of atmospheric nuclear weapons testing.

How dangerous is Strontium-90?

Strontium-90 acts much like calcium in the body and, when ingested, becomes incorporated into the bone. Very large Sr-90 sources from the former Soviet Union were responsible for severe radiation injuries in the nations of Georgia and Russia in 2001.

- High-activity Strontium-90 sources may emit dangerously high levels of radiation
- Strontium-90 that is ingested can give a high radiation dose to the bone
- Strontium-90 contamination on the skin can cause skin burns
- Strontium-90 sources should not be held in the hand at any time.

Just the facts about Strontium-90!

Sr-90

Half-life = 29 years
beta particle = 546 keV
x-ray radiation
From Y-90 daughter
beta particle = 2293 keV
gamma rays = 203, 480 keV

- Strontium-90 (abbreviated Sr-90 or ^{90}Sr) has a half-life of nearly 30 years, so an area contaminated with Sr-90 will remain contaminated for decades unless it is cleaned up.
- Sr-90 emits a single medium-energy beta particle. Sr-90 decays to Y-90, which emits moderate-energy gamma rays and a high-energy beta particle
- When in the body (if it is swallowed or inhaled), Sr-90 goes to the bones.
- Inhaled or ingested Sr-90 can be moderately dangerous
- High-activity Sr-90 sources can emit dangerous levels of x-ray radiation
- Sr-90 sources should not be held in the bare hand at any time

Radiation Fact Sheet: Strontium-90

Radiation Fact Sheet: Strontium-90

What does a Sr-90 source look like?

Sr-90 sources vary widely in size and form. Small sources are typically small metal cylinders up to an inch in diameter and half an inch tall. Large sources may be made of ceramic and encased in large devices such as the one shown in the photo.



An example of a very large Sr-90 source and its shielding

How could a terrorist use Sr-90?

- Terrorists may make a radiological dispersal device (RDD, or "dirty" bomb") by adding powdered Sr-90 to explosives; the explosion will then spread the Sr-90 to contaminate large areas. In this case, the radiation and contamination levels are not likely to be dangerously high, but there may be a moderate health risk from inhaling or ingesting Strontium-90 or by spending prolonged periods of time in highly contaminated areas.
- Terrorists may place a very large Sr-90 source in a public place, attempting to cause radiation sickness from the x-ray or gamma radiation emitted. However, prolonged exposure (several minutes) at close distance (less than a few feet) is necessary to cause radiation sickness.
- Terrorists may use radioactive Sr-90 to try to contaminate the food or water supply. If put into water, the radioactivity will probably be filtered out by the water treatment plants. Sr-90 put onto food will probably cause a moderate to high risk depending on the amount that is ingested, although washing food thoroughly prior to eating will reduce this risk significantly.

How can I protect myself from a terrorist attack with Sr-90?

- In the event of an RDD attack, you should go indoors and shut open doors and windows. Listen to the TV or radio for further instructions.
- Do not approach an irradiator or other very large Sr-90 source; maintain a distance of at least 20 feet unless radiation safety professionals perform a survey and state it is safe
- **DO NOT** attempt to drive away from the site of a radiological attack.
- If you are upwind of the attack, no further actions are necessary because the radioactivity will travel away from you.
- If you are downwind of the attack, you should change clothes and take a shower (or at least wash your hands and face) after going indoors.
- If you are outdoors and can see or hear the explosion, you should fold a handkerchief or other piece of cloth several times and breathe through it until you are indoors.
- If you have a home garden and if you are downwind of the attack, you should wash the fruits or vegetables from your garden before you eat them

Radiation Fact Sheet: Strontium-90

Radiological Fact Sheet: Controlling contamination

Risks Contamination (measured in counts per minute) measures number of "bits" of radiation that come from a given area, and each of these bits (counts) does only a tiny amount of damage. ***So even a very high level of contamination emits only a little amount of radiation, and poses very little risk.*** However, contamination that enters the body (especially inhaled) can be more dangerous and should be avoided. Working with radioactive contamination is like changing a dirty diaper – the contamination won't kill you, but you still want avoid getting it on you if you can.

Ambulance and treatment area contamination control

1. Wrap patient in blankets to contain contamination and reduce contamination of facilities
2. Establish dedicated routes for transporting contaminated patients
3. Establish dedicated areas for decontamination and contaminated patient care
4. Line dedicated routes and rooms with plastic to reduce contamination of fixed surfaces
5. Do not use vehicles or equipment for non-contaminated patients unless necessary

Contamination control actions in the Emergency Department

1. Wear proper PPE and respiratory protection (see the PPE fact sheet)
2. Lay down impermeable plastic floor covering if possible to establish a contamination control corridor directly from ED entrance to treatment rooms
3. Move stretchers and gurneys along the contamination control corridor whenever possible
4. Use dedicated rooms for all contaminated patients to minimize the spread of contamination to other parts of the hospital
5. Leave controlled areas only at contamination control checkpoints
6. Remove PPE and conduct radiological survey upon leaving the controlled area when the patient's condition permits

Working with contaminated patients

1. **Treat life-threatening injuries first**.
2. Try to avoid getting contamination into open wounds
    a. Rinse with saline, de-ionized water, clean with alcohol wipes if possible
3. If time permits, wrap heavily contaminated persons in sheets or blankets
4. If time permits, remove patient's clothing or dress in coveralls or "bunny suit"
5. When possible, wear appropriate PPE when treating patients
    a. Surgical gloves, N95 mask or equivalent, shoe covers, and coveralls
6. Use disposable equipment (blood pressure cuffs, for example) when possible
7. Assume that all equipment used on a patient is radioactively contaminated
    a. Decontaminate before using with another patient if possible
    b. Use without decontamination if necessary to save a life

Radiological Fact Sheet: Controlling contamination

Radiological Fact Sheet: Controlling contamination

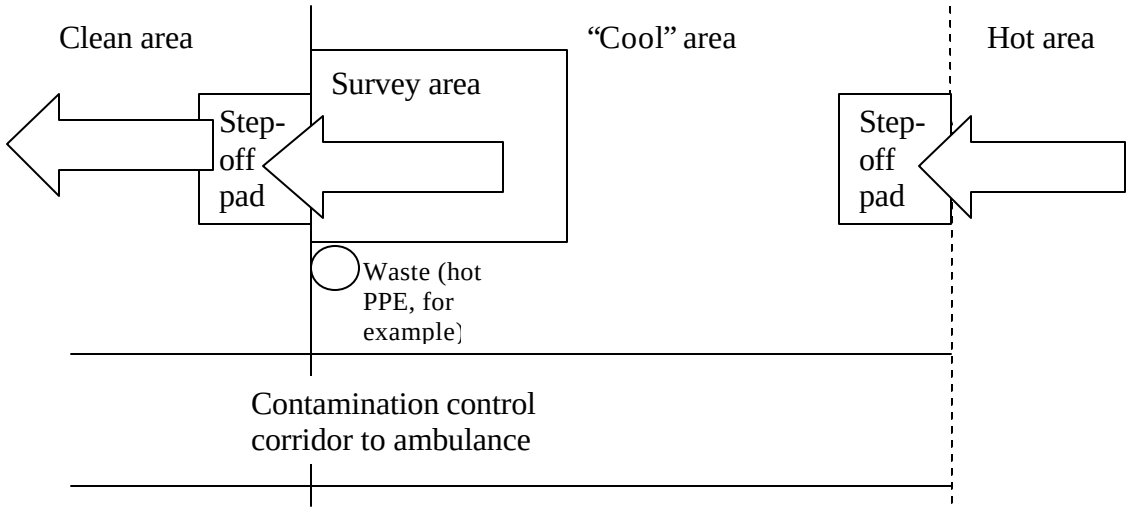
Leaving a controlled area - patient

(Items in bold ***must*** be performed, others ***should*** be followed when time and personnel permit)

1. **Enter "hot" side of exit point**
2. Log names of responder and patient
3. Transfer patient to "clean" stretcher OR survey and decontaminate stretcher
    a. Refer to survey and decontamination fact sheets
    b. If possible, wrap patient in clean sheets or blankets prior to transfer
4. **Transfer patient to hospital or field facility for further medical care**
5. Perform contamination survey of exit point and the transfer route when ambulance leaves
6. Prepare for next patient

Leaving a controlled area – responders

1. **Enter "hot" side of exit point**
2. Log name of responder entering the exit point
3. **Survey outer gloves or hands for contamination**
4. **Survey coveralls or outer clothing for radioactive contamination**
    a. If contaminated, remove coveralls or outer clothing and place in radioactive waste container or plastic bag
5. Step to "cold" boundary of exit point
6. **Remove shoe covers while stepping over boundary to "cold" side of exit point**
7. **Remove gloves inside out and place into radioactive waste container or plastic bag**
8. Survey whole body, concentrating on hands, feet, face, knees, elbows, and seat of pants
9. Survey exit point and step-off pad(s) periodically and decontaminate as necessary



Radiological Fact Sheet: Controlling contamination

Radiological Fact Sheet: Radiological Decontamination

Decontamination

If there is a radiological attack or incident, you may be working in a contaminated area or taking care of contaminated victims. This is probably going to cause you to become contaminated. Contamination can be reduced by wearing proper PPE (see the PPE fact sheet). But you might still need to decontaminate yourself, a victim, or your equipment.

Decontaminating yourself (after performing a whole-body survey to locate contamination) – take those steps that are possible with available materials

1. Remove contaminated clothing and place into radioactive waste container
2. Survey beneath contaminated areas on clothing
3. If skin is contaminated, immediately notify health and safety personnel
4. If multiple areas are contaminated, decontaminate areas with open cuts or wounds first, body orifices (e.g. mouth, nose) next, and contaminated skin beginning with the most-contaminated
5. Flush contaminated areas with saline or clean water
6. Wash with mild soap and cool to warm water
    a. Large areas of contaminated skin may require a shower
7. Monitor every few washes to confirm that counts are dropping – if so, it means that the decontamination is working
8. If these decontamination efforts are not effective, sealing the contaminated area in a plastic bag or wrap for several hours is often effective (not recommended with facial contamination)
9. If this does not reduce contamination levels, request assistance from radiation safety personnel
10. Collect liquids, rags, wipes as radioactive waste

Patient decontamination

1. Remove patient's clothing, if possible
2. Rinse contaminated areas with saline solution or de-ionized water
3. Shower or bathe patient, using mild soap and cool to warm water
4. Give sponge bath, discard sponge or washcloth as radioactive waste
5. Flush open wounds with saline solution or de-ionized water
6. Use standard sterile practices prior to administering injections, suturing, or other practices that puncture or break the skin

Radiological Fact Sheet: Radiological Decontamination

Decontaminating equipment

1. Smooth surfaces (glass, plastic, metal) can be decontaminated by washing or wiping as described below
2. Begin by wiping with rag or cloth dampened with water or alcohol
3. If still contaminated after several attempts, try wiping with a commercial product (window cleaner, oven cleaner, etc.)
4. Another technique is to use tape to remove loose contamination by pressing the sticky side of the tape to contaminated areas
5. If still contaminated, try wiping with specialty product such as Radiac Wash, IsoClean, or Counts Off or with a chelating agent such as EDTA
6. If still contaminated, contamination is probably fixed in the object; if less than 5,000 counts per minute above background, may continue to use

7. Porous surfaces (wood, cloth, some ceramics, etc.) cannot be decontaminated by washing or wiping
8. Begin with pressing tape to contaminated areas
9. Wipe with water, alcohol, and other agents as noted above
10. If this is unsuccessful, item may be soaked in a cleaning solution or placed in an ultrasonic sink
11. As a last resort soft items (wood, plastic, lead, etc.) may be shaved with a sharp knife to remove contaminated areas. Contaminated sections of fabric or paper can be cut out and the remainder used.

12. If contamination is fixed in equipment (such as linens or stretcher coverings), and the equipment must be used, cover the contaminated area with plastic or clean cloth and continue using the equipment as long as necessary
13. Large areas (such as ambulance interiors, floors) may be decontaminated by wiping with a sponge or rags soaked in soapy water, detergent, or other cleaning solutions

Radiological Fact Sheet: Using Radiation Instruments

Identifying alpha, beta, or gamma radiation

1. Turn on the meter and look at the scale BEFORE going to the scene to see what background radiation levels are (see the other side of this fact sheet)
2. When surveying patients, take radiation readings on the ground or on victims
3. If the readings are elevated, perform the following tests
    a. Put a piece of ***paper*** beneath the probe. If the meter reading drops to background, it is ***alpha*** radiation (see the fact sheet on alpha radioactivity). If the reading stays the same, go to step B
    b. Put your ***hand*** beneath the probe. If the meter reading drops to background, it is ***beta*** radiation (see the fact sheets on beta radioactivity and Sr-90).
    c. If the reading stays the ***same***, you have ***gamma*** radiation (see the fact sheet on gamma radioactivity)

What the meter readings mean

1. If the **radiation level** is in excess of:
    a. 1000 r/hr are potentially lethal – leave area immediately
    b. 500 r/hr can cause severe radiation sickness – enter only to save lives or to take actions that are certain to have great benefit
    c. 100 r/hr can cause mild radiation sickness and can cause a person to exceed legal dose limits – enter only to rescue victims or to take actions to save property
    d. 10 r/hr or less will have no likely health effects, but may cause a person to exceed regulatory dose limits – monitor exposure and exit area before dose limit is reached
    e. Measure radiation levels with an ion chamber or microR meter

2. If the contamination levels are in excess of:
    a. 500,000 counts per minute (cpm) – contamination may be resuspended; wear full anticontamination clothing (see PPE fact sheet) and respiratory protection
    b. 1500 cpm in any single location – must be decontaminated prior to release for unrestricted use
    c. 500 cpm average over large areas – must be decontaminated prior to release

How to perform a contamination survey

1. Turn on the meter, check the battery, and take the switch to the highest scale (usually x1000 or x10,000)
2. Turn on the audible response
3. Hold detector < ½ inch from the item being surveyed and move it at about 1-2 inches per second
4. Turn switch to lower scales until the meter reading is less than ¾ of the full scale
5. Record results on a survey map and note areas with high contamination levels (more than 1000 cpm)

How to perform a radiation survey

1. Turn on meter, check battery, take switch to highest setting
2. Hold detector or meter about waist height and walk slowly through area,
3. Note areas with elevated readings on survey maps

Radiological Fact Sheet: Using Radiation Instruments

Radiological Fact Sheet: Using Radiation Instruments



Sodium iodide (NaI) probe for **gamma contamination** and radiation surveys. This should be used for contamination surveys unless it is attached to a meter that has been calibrated to measure in radiation levels (this information should be noted on the instrument calibration records. **Record results in CPM.**



Geiger-Mueller (GM) "pancake" probe for **beta and gamma contamination surveys. Record results in CPM**.



Geiger-Mueller (GM) "hot dog" probe for **beta and gamma contamination** surveys. This may be used for measuring radiation levels only if the meter was calibrated for the isotope (e.g. Cs-137) present on the patient or in the room being monitored. **Record results in cpm.**



Zinc sulfide (ZnS) **alpha** scintillation probe. The window on this probe is exceptionally fragile and must be protected from accidental puncture. **Record results in cpm**.



Ion chamber. This detector is used to measure radiation levels from beta (with bottom window open) or gamma (with bottom window closed) radiation sources. **Record results in mr/hr.**

Radiological Fact Sheet: Using Radiation Instruments

Medical Fact Sheet: Further Information and References

Books on the Medical Management of Radiological Emergencies

Ricks, RC; Berger, ME; O'Hara, FM. *The Medical Basis for Radiation-Accident Preparedness: The Clinical Care of Victims*; Parthenon Publishing, New York. 2002

Guzev, IA; Guskova, AK; Mettler, FA. *Medical Management of Radiation Accidents, 2nd Edition*. CRC Press, Boca Raton. 2001

Brodsky, A; Johnson, RH; Goans, RE. *Public Protection from Nuclear, Chemical, and Biological Terrorism* (textbook for the 2004 Health Physics Society Summer School). Medical Physics Publishing, Madison WI. 2004

Veenema, TG. *Disaster Nursing and Emergency Preparedness for Chemical, Biological, and Radiological Terrorism*. Springer Publishing Company, New York. 2003

National Council on Radiation Protection and Measurements Report # 65, *Management of Persons Accidentally Contaminated with Radionuclides*, April, 1980.

National Council on Radiation Protection and Measurements Report #138, *Management of Terrorist Events Involving Radioactive Material*. October, 2001

National Research Council. *Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident*, National Academies Press, Washington DC, 2004

Web sites addressing response to radiological terrorism

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

Armed Forces Radiobiology Research Institute (http://www.afrri.usuhs.mil/)

Centers for Disease Control (http://www.bt.cdc.gov/radiation/index.asp)

New York City DOHMH (http://www.nyc.gov/html/doh/html/bt/bt_radio.html)

Health Physics Society Homeland Security Committee (http://hps.org/hsc/index.html)

Medical Fact Sheet: Further Information and References

Medical Fact Sheet: Further Information and References

Specific papers and web sites addressing specific issues regarding the medical response to radiological terrorism

Marcus, CS. Administration of decorporation drugs to treat internal radionuclide contamination *Medical emergency response to radiologic incidents*, published on-line at http://www.acnp-cal.org/DMAT-AdmDecorpDrugsIntRadContam12-01-03.pdf

REAC/TS guidance on administration of Ca and Zn DTPA is available on-line at http://www.orau.gov/reacts/calcium.htm and http://www.orau.gov/reacts/zinc.htm, respectively

REAC/TS guidance on administration of Prussian Blue is available on-line at http://www.orau.gov/reacts/prussian.htm

Veenema, TG; Karam, PA. *Radiologic Incidents and Emergencies*, American Journal of Nursing 103(5):32-40

Medical Fact Sheet: Further Information and References

Radiation Fact Sheet: Am-241 Contamination

Overview

Am-241 is an isotope frequently used in gauges for industrial process control, for investigating soil properties, and in home smoke detectors. Am-241 is usually present as a powder inside of radioactive sources or impregnated into foil in smoke detectors – the powder can be easily dispersible and constitutes a **potentially serious inhalation risk**. Sources containing Am-241 range in activity from very small to relatively high-activity. **Am-241 is highly radiotoxic when inhaled and can pose a grave inhalation hazard**.

Medical personnel – risks and precautions

1. Am-241 contamination poses no external radiation hazard to medical personnel
2. Am-241 may pose a risk if inhaled
3. Medical personnel should take **Universal Precautions** when working with patients
4. Am-241 contamination on the bare skin can lead to moderate radiation dose in very localized areas
5. All personnel present should wear respiratory protection (N-95 masks) if patients are heavily contaminated
6. Take routine contamination control precautions (see Contamination Controls fact sheet)

Risks to patients

1. Inhaled Am-241 can give a dangerously high radiation dose to the lungs
2. Ingested Am-241 can give a moderate radiation dose to the stomach and intestinal tract
3. Ingested or inhaled Am-241 will give a very high radiation dose to the liver and the bone
4. Distributed Am-241 contamination on skin is not dangerous
5. Am-241 that is absorbed through open wounds or burns may pose a high risk to patients

Biokinetics and target organs

1. Less than 1% of Am in the lungs or GI tract is absorbed into the blood
2. 45% of Am in the blood goes to the liver and is retained with a biological half-life of 20 years
3. 45% goes to the bone and is retained with a biological half-life of 50 years
4. 10% of Am in the blood goes directly to excreta
5. Am is excreted through the urine and feces

Decorporation agents

Parenteral Ca-DTPA or Zn-DTPA. In normal, healthy, non-pregnant adults with normal bone marrow and renal function, the dose to use is 1 gm in 250 ml normal saline or 5% dextrose in water, IV over 1 hour. No more than 1 dose per day should be used, and the dose should ***not*** be fractionated. May use for several days to a week in most cases without toxic effects.

Physical data

Half-life	432 years	**Emissions**	alpha (5.5 MeV)
Dose rate	13 mrem/hr from 1 Curie at 1 meter		gamma (60 keV)

Radiation Fact Sheet: Am-241 Contamination

Radiation Fact Sheet: Am-241 Contamination

Contaminated patients

It is best to survey for Am-241 with an alpha detector or a thin-crystal sodium iodide probe.

Actions			
Contamination levels (patient)	**Patient in danger of losing life, limb, or sight**	**Moderate injuries**	**Light injuries**
Heavy (>100,000 cpm)	1. Treat life-threatening injuries 2. Take staff contamination control measures 3. Control patient contamination if it does not interfere with health 4. Decontaminate patient after treatment complete	1. Decontaminate in field 2. Remove clothing or wrap in blanket or sheets 3. Take staff contamination control measures 4. Treat injuries	1. Decontaminate patient in field or in decon area 2. Remove and replace patient clothing 3. Survey skin with alpha detector or thin-crystal sodium iodide detector 4. Decontaminate skin 5. Treat injuries
Moderate (10,000–100,000 cpm)			
Light (<10,000 cpm)		1. Care for most serious injuries first 2. Take staff contamination control measures	

Samples

All radiation cases		
Sample	**How obtained**	**Comments**
CBC and differential	Draw from non-contaminated area	Routine sample analysis procedures
Routine urinalysis	Do not contaminate sample	
Absolute lymphocytes every 6 hrs x 8	Draw from non-contaminated area	
External contamination only		
Sample	**How obtained**	**Comments**
Swab orifices	Use moistened swabs	Count with alpha detector or low-energy gamma probe (thin-crystal sodium iodide – NaI – probe)
Swab wounds and sample dressings	Use swabs or syringes	
Internal contamination		
Sample	**How obtained**	**Comments**
Urine – 24-hour specimen x 4 days	Use 24 hour urine container	Take care not to contaminate sample while collecting sample
Feces – 24-hr specimen x 4 days		
Quick nasal or oral count	Use alpha probe to survey nostrils and mouth	High counts could indicate Am-241 inhalation

Radiological Triage

Am-241 is not likely to produce life-endangering radiation dose to patients unless inhaled. Inhaled Am-241 can pose a grave hazard to patients

1. External (skin and clothing) contamination only – patients are in no danger from radiation injury
2. Internal (lung) contamination – can produce very high radiation dose – if inhalation is suspected, begin decorporation therapy at the earliest opportunity and contact the REAC/TS center at Oak Ridge
3. Radiation dose < 100 rem (whole body) – do not admit unless non-radiological factors necessitate
4. Radiation dose < 800 rem (whole body) – possible immune suppression – admit and treat with antibiotics
5. Radiation dose >1000 rem (whole body) – lethal exposure – sedate and make comfortable

Radiation Fact Sheet: Am-241 Contamination

Radiation Fact Sheet: Ra-226 Contamination

Overview

Ra-226 is an isotope with former wide use in gauges for industrial process control, for investigating soil properties, and in medical therapy. Ra-226 is usually present as a sealed radioactive source that may be ground into a powder for greater dispersibility or as a powder sealed within a source. Sources containing Ra-226 range in activity from very small to relatively high-activity. **Ra-226 is very radiotoxic when inhaled and can pose a serious inhalation hazard.**

Medical personnel – risks and precautions

1. Ra-226 contamination poses no external radiation hazard to medical personnel
2. Ra-226 may pose a risk if inhaled
3. Medical personnel should take **Universal Precautions** when working with patients
4. Ra-226 contamination on the bare skin can lead to moderate radiation dose in very localized areas
5. All personnel present should wear respiratory protection (N-95 masks) if patients are heavily contaminated
6. Take routine contamination control precautions (see Contamination Controls fact sheet)

Risks to patients

1. Inhaled Ra-226 can give a dangerously high radiation dose to the lungs
2. Ingested Ra-226 can give a moderate radiation dose to the bone
3. Ingested or inhaled Ra-226 will give a very high radiation dose to the bone
4. Distributed Ra-226 contamination on skin is not dangerous
5. Ra-226 that is absorbed through open wounds or burns may pose a moderate risk to patients

Biokinetics and target organs

1. About 20% of ingested or inhaled Ra-226 enters the blood
2. Ra-226 is assumed to behave similarly to Ca in the body
3. Over 90% of Ra-226 that enters the blood goes to mineralized bone where it is retained for months to years
4. 98% of Ra-226 in the body is excreted in feces with the remainder excreted in the urine

Decorporation agents

Consider administering generous doses of oral calcium to reduce gastrointestinal absorption and increase urinary excretion. Alginates are also useful to reduce gastrointestinal absorption.

Physical data

Half-life	1600 years	**Emissions**	alpha (4.8 MeV)
Dose rate	2.8 mrem/hr from 1 Curie at 1 meter		gamma (186 keV)

Radiation Fact Sheet: Ra-226 Contamination

Radiation Fact Sheet: Ra-226 Contamination

Contaminated patients

It is best to survey for Ra-226 with an alpha detector or a thin-crystal sodium iodide probe.

<table>
<tr><th colspan="4">Actions</th></tr>
<tr><th>Contamination levels (patient)</th><th>Patient in danger of losing life, limb, or sight</th><th>Moderate injuries</th><th>Light injuries</th></tr>
<tr><td>Heavy (>100,000 cpm)</td><td rowspan="3">1. Treat life-threatening injuries
2. Take staff contamination control measures
3. Control patient contamination if it does not interfere with health
4. Decontaminate patient after treatment complete</td><td rowspan="2">1. Decontaminate in field
2. Remove clothing or wrap in blanket or sheets
3. Take staff contamination control measures
4. Treat injuries</td><td rowspan="3">1. Decontaminate patient in field or in decon area
2. Remove and replace patient clothing
3. Survey skin with alpha or sodium iodide detector
4. Decontaminate skin
5. Treat injuries</td></tr>
<tr><td>Moderate (10,000–100,000 cpm)</td></tr>
<tr><td>Light (<10,000 cpm)</td><td>1. Care for most serious injuries first
2. Take staff contamination control measures</td></tr>
</table>

Samples

<table>
<tr><th colspan="3">All radiation cases</th></tr>
<tr><th>Sample</th><th>How obtained</th><th>Comments</th></tr>
<tr><td>CBC and differential</td><td>Draw from non-contaminated area</td><td rowspan="3">Routine sample analysis procedures</td></tr>
<tr><td>Routine urinalysis</td><td>Do not contaminate sample</td></tr>
<tr><td>Absolute lymphocytes every 6 hrs x 8</td><td>Draw from non-contaminated area</td></tr>
<tr><th colspan="3">External contamination only</th></tr>
<tr><th>Sample</th><th>How obtained</th><th>Comments</th></tr>
<tr><td>Swab orifices</td><td>Use moistened swabs</td><td rowspan="2">Count with alpha or sodium iodide gamma probe</td></tr>
<tr><td>Swab wounds and sample dressings</td><td>Use swabs or syringes</td></tr>
<tr><th colspan="3">Internal contamination</th></tr>
<tr><th>Sample</th><th>How obtained</th><th>Comments</th></tr>
<tr><td>Urine – 24-hour specimen x 4 days</td><td rowspan="2">Use 24 hour urine container</td><td rowspan="2">Take care not to contaminate sample while collecting sample</td></tr>
<tr><td>Feces – 24-hr specimen x 4 days</td></tr>
<tr><td>Quick nasal or oral count</td><td>Use alpha probe to survey nostrils and mouth</td><td>High counts could indicate Ra-226 inhalation</td></tr>
</table>

Radiological Triage

Ra-226 is not likely to produce life-endangering radiation dose to patients unless inhaled. Inhaled Ra-226 can pose a hazard to patients

1. External (skin and clothing) contamination only – patients are in no danger from radiation injury
2. Internal (lung) contamination – can produce high radiation dose – if inhalation is suspected, begin decorporation therapy at the earliest opportunity and contact the REAC/TS center at Oak Ridge
3. Radiation dose < 100 rem (whole body) – do not admit unless non-radiological factors necessitate
4. Radiation dose < 800 rem (whole body) – possible immune suppression – admit and treat with antibiotics
5. Radiation dose >1000 rem (whole body) – lethal exposure – sedate and make comfortable

Radiation Fact Sheet: Ra-226 Contamination

Radiation Fact Sheet: Cf-252 Contamination

Overview

Cf-252 is an isotope with limited use in gauges for industrial process control and in research. Cf-252 is usually present as a sealed radioactive source that may be ground into a powder for greater dispersibility or as a powder sealed within a source. Sources containing Cf-252 range in activity from low-activity to relatively high-activity. **Cf-252 is very radiotoxic when inhaled and can pose a serious inhalation hazard.**

Medical personnel – risks and precautions

1. Cf-252 contamination poses no external radiation hazard to medical personnel
2. Cf-252 may pose a risk if inhaled
3. Medical personnel should take **Universal Precautions** when working with patients
4. Cf-252 contamination on the bare skin can lead to moderate radiation dose in very localized areas
5. All personnel present should wear respiratory protection (N-95 masks) if patients are heavily contaminated
6. Take routine contamination control precautions (see Contamination Controls fact sheet)

Risks to patients

1. Inhaled Cf-252 can give a dangerously high radiation dose to the lungs, liver, and bone
2. Ingested Cf-252 can give a very high radiation dose to the bone and liver
3. Distributed Cf-252 contamination on skin is not dangerous
4. Cf-252 that is absorbed through open wounds or burns may pose a moderate risk to patients

Biokinetics and target organs

1. Less than 1% of ingested or inhaled Cf-252 enters the blood
2. 65% of Cf-252 that enters the blood goes to the bone and is retained with a biological half-life of 50 years
3. 24% of Cf-252 that enters the blood goes to the liver and is retained with a biological half-life of 20 years
4. 10% of Cf-252 that enters the blood immediately goes to excreta

Decorporation agents

Ca DTPA and Zn DTPA have been successfully used in actinide decorporation. Ca DTPA is initially much more effective and is preferred unless contraindicated. After about 24 hours, both are equally effective. Each dose should be 1 gram of Zn-DTPA. The route of administration may be either intravenous infusion of the undiluted solution over a period of 3-4 minutes, intravenous infusion (in 100-250 ml D_5W, Ringers Lactate, or normal saline), or inhalation in a nebulizer (1:1 dilution with water or saline). Intravenous administration should not be protracted over more than 2 hours.

Physical data

Half-life	2.64 years	**Emissions**	alpha (6.1 MeV)
Dose rate	42 mrem/hr from 1 Curie at 1 meter		no gamma

Radiation Fact Sheet: Cf-252 Contamination

Radiation Fact Sheet: Cf-252 Contamination

Contaminated patients

It is best to survey for Cf-252 with an alpha detector.

Actions			
Contamination levels (patient)	**Patient in danger of losing life, limb, or sight**	**Moderate injuries**	**Light injuries**
Heavy (>100,000 cpm)	1. Treat life-threatening injuries 2. Take staff contamination control measures 3. Control patient contamination if it does not interfere with health 4. Decontaminate patient after treatment complete	1. Decontaminate in field 2. Remove clothing or wrap in blanket or sheets 3. Take staff contamination control measures 4. Treat injuries	1. Decontaminate patient in field or in decon area 2. Remove and replace patient clothing 3. Survey skin with alpha or sodium iodide detector 4. Decontaminate skin 5. Treat injuries
Moderate (10,000–100,000 cpm)			
Light (<10,000 cpm)		1. Care for most serious injuries first 2. Take staff contamination control measures	

Samples

All radiation cases		
Sample	**How obtained**	**Comments**
CBC and differential	Draw from non-contaminated area	Routine sample analysis procedures
Routine urinalysis	Do not contaminate sample	
Absolute lymphocytes every 6 hrs x 8	Draw from non-contaminated area	
External contamination only		
Sample	**How obtained**	**Comments**
Swab orifices	Use moistened swabs	Count with alpha or sodium iodide gamma probe
Swab wounds and sample dressings	Use swabs or syringes	
Internal contamination		
Sample	**How obtained**	**Comments**
Urine – 24-hour specimen x 4 days	Use 24 hour urine container	Take care not to contaminate sample while collecting sample
Feces – 24-hr specimen x 4 days		
Quick nasal or oral count	Use alpha probe to survey nostrils and mouth	High counts could indicate Cf-252 inhalation

Radiological Triage

Cf-252 is not likely to produce life-endangering radiation dose to patients unless inhaled.
Inhaled Cf-252 can pose a hazard to patients

1. External (skin and clothing) contamination only – patients are in no danger from radiation injury
2. Internal (lung) contamination – can produce high radiation dose – if inhalation is suspected, begin decorporation therapy at the earliest opportunity and contact the REAC/TS center at Oak Ridge
3. Radiation dose < 100 rem (whole body) – do not admit unless non-radiological factors necessitate
4. Radiation dose < 800 rem (whole body) – possible immune suppression – admit and treat with antibiotics
5. Radiation dose >1000 rem (whole body) – lethal exposure – sedate and make comfortable

Radiation Fact Sheet: Cf-252 Contamination

Radiation Fact Sheet: H-3 (tritium) Contamination

Overview

Tritium is an isotope used in research and in some self-luminous products (such as exit signs). It is also found in nuclear weapons and in hydrogen fusion research facilities. H-3 is typically present as a gas, tritiated water, or as a solid, none of which normally poses an internal or external health risk. Tritium moves with water in the body, so in the event of an uptake, extra fluid intake will help dilute tritium.

Medical personnel – risks and precautions

1. H-3 ***contamination*** poses no external radiation hazard to medical personnel
2. Medical personnel should take **Universal Precautions** when working with patients (in particular, avoid direct skin contact and contact with excreta and bodily fluids)
3. Take routine contamination control precautions (see appropriate fact sheet)

Risks to patients

1. Inhaled and ingested H-3 causes low radiation dose to the whole body
2. H-3 is easily absorbed through the skin and distributes evenly throughout the body

Biokinetics and target organs

1. Nearly 100% of H-3 is absorbed through the lungs, GI tract, or open wounds
2. Tritium in the body leaves with a biological half-life of about 10 days

In case of an uptake

Tritium will follow water through the body. In case of uptake, encourage fluid intake to dilute H-3 in the body and to increase excretion of tritium via urine.

Physical data

Half-life	12.27 years	**Emissions**	Beta (18 keV)
Dose rate	beta-emitter – no external dose rate; ingesting 1 Ci gives a whole-body dose of 64 rem		

Radiation Fact Sheet: H-3 (tritium) Contamination

Radiation Fact Sheet: H-3 (tritium) Contamination

Contaminated patients

It is not possible to survey directly for H-3 with a Geiger counter because of the very low energy beta radiation. To check for contamination it is necessary to obtain swabs and count in a liquid scintillation counter.

Actions			
Contamination levels (patient)	**Patient in danger of losing life, limb, or sight**	**Moderate injuries**	**Light injuries**
Heavy (>100,000 cpm)	1. Treat life-threatening injuries 2. Take staff contamination control measures 3. Control patient contamination if it does not interfere with health 4. Decontaminate patient after treatment complete	1. Decontaminate in field 2. Remove clothing or wrap in blanket or sheets 3. Take staff contamination control measures 4. Treat injuries	1. Decontaminate patient in field or in decon area 2. Remove and replace patient clothing 3. Cannot survey with simple field equipment – assume patient is contaminated 4. Decontaminate skin 5. Treat injuries
Moderate (10,000–100,000 cpm)			
Light (<10,000 cpm)		1. Care for most serious injuries first 2. Take staff contamination control measures	

Samples

All radiation cases		
Sample	**How obtained**	**Comments**
CBC and differential	Draw from non-contaminated area	Routine sample analysis procedures
Routine urinalysis	Do not contaminate sample	
Absolute lymphocytes every 6 hrs x 8	Draw from non-contaminated area	
External contamination only		
Sample	**How obtained**	**Comments**
Swab orifices	Use moistened swabs	Count with liquid scintillation counter (tritium window) or proportional counter (ß channel)
Swab wounds and sample dressings	Use swabs or syringes	
Internal contamination		
Sample	**How obtained**	**Comments**
Urine – 24-hour specimen x 4 days	Use 24 hour urine container	Take care not to contaminate sample during collection
Feces – 24-hr specimen x 4 days		
May detect H-3 in perspiration a few hours after uptake	Swab skin, count in liquid scintillation counter	High counts could indicate uptake of H-3

Radiological Triage

Tritium ingestion, inhalation, or contamination is very unlikely to pose any risk to the patient

1. External (skin and clothing) contamination only – patients are in no danger from radiation injury
2. Internal (lung) contamination – patients may receive high dose; quantify internal dose and admit if needed
3. Radiation dose < 100 rem (whole body) – do not admit unless non-radiological factors necessitate
4. Radiation dose < 800 rem (whole body) – possible immune suppression – admit and treat with antibiotics
5. Radiation dose >1000 rem (whole body) – lethal exposure – sedate and make comfortable

Radiation Fact Sheet: H-3 (tritium) Contamination

Radiation Fact Sheet: P-32 Contamination

Overview

P-32 is an isotope frequently used in biological, medical, and chemical research. It is also used less frequently in medicine as a sealed source or as a liquid radiopharmaceutical. P-32 is usually present as a clear liquid that is easily dispersible, making it a **potential inhalation, ingestion, or contamination hazard**. P-32 is almost invariably found in small vials with low to moderate levels of radioactivity. Vials or syringes containing P-32 may be handled with the hands, but only while wearing gloves to avoid skin contamination. P-32 beta radiation has a range of only 1 cm in tissue.

Medical personnel – risks and precautions

1. P-32 contamination poses no external radiation hazard to medical personnel
2. Medical personnel should take **Universal Precautions** when working with patients
3. P-32 contamination on the bare skin can lead to very localized high doses
4. Consider wearing respiratory protection (N-95 masks) if patients are heavily contaminated
5. Take routine contamination control precautions (see appropriate fact sheet)

Risks to patients

1. Inhaled and ingested P-32 contamination can give high radiation dose to the bone and marrow
2. Distributed P-32 contamination on skin is not dangerous, although droplets of P-32 can give high doses to the contaminated area
3. P-32 that is absorbed through open wounds or burns is not normally a high risk to patients

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Biokinetics and target organs

1. About 80% of ingested or inhaled P-32 is absorbed into the blood
2. 30% of P-32 in the blood is deposited in mineral bone and retained permanently
3. 40% of P-32 in the blood goes to soft tissues with a biological half-life of 19 days
4. 15% of P-32 in the blood is excreted directly
5. 15% of P-32 in the blood goes to intracellular fluids, where it is retained with a biological half-life of 2 days

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Decorporation agents

Oral Na phosphate or K phosphate (K-phos Neutral) 250-500 mg by mouth with water at meal time and at bed time. Pediatric dose is 250 mg.

Physical data

Half-life	14 days	**Emissions**	Beta (1.71 MeV)
Dose rate	not applicable to beta emitters		no gamma

Radiation Fact Sheet: P-32 Contamination

Radiation Fact Sheet: P-32 Contamination

Contaminated patients

Actions			
Contamination levels (patient)	**Patient in danger of losing life, limb, or sight**	**Moderate injuries**	**Light injuries**
Heavy (>100,000 cpm)	1. Treat life-threatening injuries 2. Take staff contamination control measures 3. Control patient contamination if it does not interfere with health 4. Decontaminate patient after treatment complete	1. Decontaminate in field 2. Remove clothing or wrap in blanket or sheets 3. Take staff contamination control measures 4. Treat injuries	1. Decontaminate patient in field or in decon area 2. Remove and replace patient clothing 3. Survey skin with Geiger counter 4. Decontaminate skin 5. Treat injuries
Moderate (10,000–100,000 cpm)			
Light (<10,000 cpm)		1. Care for most serious injuries first 2. Take staff contamination control measures	

Samples

All radiation cases		
Sample	**How obtained**	**Comments**
CBC and differential	Draw from non-contaminated area	Routine sample analysis procedures
Routine urinalysis	Do not contaminate sample	
Absolute lymphocytes every 6 hrs x 8	Draw from non-contaminated area	
External contamination only		
Sample	**How obtained**	**Comments**
Swab orifices	Use moistened swabs	Count with Geiger or count in liquid scintillation counter set for P-32
Swab wounds and sample dressings	Use swabs or syringes	
Internal contamination		
Sample	**How obtained**	**Comments**
Urine – 24-hour specimen x 4 days	Use 24 hour urine container	Take care not to contaminate sample while collecting sample
Feces – 24-hr specimen x 4 days		
Quick nasal or oral count	Use Geiger probe to count nostrils or mouth	High counts could indicate P-32 inhalation

Radiological Triage

P-32 is not likely to produce life-endangering radiation dose to patients

1. External (skin and clothing) contamination only – patients are in no danger from radiation injury
2. Internal (lung) contamination – patients may receive high dose; quantify internal dose and admit if needed
3. Radiation dose < 100 rem (whole body) – do not admit unless non-radiological factors necessitate
4. Radiation dose < 800 rem (whole body) – possible immune suppression – admit and treat with antibiotics
5. Radiation dose >1000 rem (whole body) – lethal exposure – sedate and make comfortable

Radiation Fact Sheet: P-32 Contamination

Radiation Fact Sheet: S-35 Contamination

Overview

S-35 is an isotope frequently used in biological, medical, and chemical research. S-35 is usually present as a clear liquid that is easily dispersible, making it a **potential inhalation, ingestion, or contamination hazard**. S-35 is almost invariably found in small plastic vials with relatively low to moderate levels of radioactivity. Vials or syringes containing S-35 may be handled with the hands, but only while wearing gloves to avoid skin contamination. S-35 beta radiation has a range of a few mm in tissue.

Medical personnel – risks and precautions

1. S-35 contamination poses no external radiation hazard to medical personnel
2. Medical personnel should take **Universal Precautions** when working with patients
3. S-35 contamination on the bare skin can lead to moderate radiation dose in very localized areas
4. Consider wearing respiratory protection (N-95 masks) if patients are heavily contaminated
5. Take routine contamination control precautions (see appropriate fact sheet)

Risks to patients

1. Inhaled insoluble S-35 can give moderate radiation dose to the lungs
2. Ingested insoluble S-35 can give a moderate radiation dose to the stomach and intestinal tract
3. Soluble S-35, whether ingested or inhaled, gives a relatively low dose to the entire body
4. Distributed S-35 contamination on skin is not dangerous
5. S-35 that is absorbed through open wounds or burns is not normally a high risk to patients

Biokinetics and target organs

1. About 80% of ingested or inhaled S-35 is absorbed into the blood
2. 80% of S-35 that enters the blood goes directly to excreta
3. 20% of S-35 that enters the blood is distributed evenly to soft tissues and retained with biological half-lives of 20 days (15%) and 2000 days (5%)

Decorporation agents

None recommended by FDA or other organizations

Physical data

Half-life	87 days	**Emissions**	Beta (167 keV)
Dose rate	not applicable for pure beta emitters		no gamma

Radiation Fact Sheet: S-35 Contamination

Radiation Fact Sheet: S-35 Contamination

Contaminated patients

Direct surveys for S-35 are difficult, even with a Geiger counter, because of the low energy of the emitted beta radiation. It is best to take swabs and count in a liquid scintillation counter

Actions			
Contamination levels (patient)	**Patient in danger of losing life, limb, or sight**	**Moderate injuries**	**Light injuries**
Heavy (>100,000 cpm)	1. Treat life-threatening injuries 2. Take staff contamination control measures 3. Control patient contamination if it does not interfere with health 4. Decontaminate patient after treatment complete	1. Decontaminate in field 2. Remove clothing or wrap in blanket or sheets 3. Take staff contamination control measures 4. Treat injuries	1. Decontaminate patient in field or in decon area 2. Remove and replace patient clothing 3. Survey skin with Geiger counter or take swabs and count in liquid scintillation counter 4. Decontaminate skin 5. Treat injuries
Moderate (10,000–100,000 cpm)			
Light (<10,000 cpm)		1. Care for most serious injuries first 2. Take staff contamination control measures	

Samples

All radiation cases		
Sample	**How obtained**	**Comments**
CBC and differential	Draw from non-contaminated area	Routine sample analysis procedures
Routine urinalysis	Do not contaminate sample	
Absolute lymphocytes every 6 hrs x 8	Draw from non-contaminated area	
External contamination only		
Sample	**How obtained**	**Comments**
Swab orifices	Use moistened swabs	Count with Geiger or count in liquid scintillation counter set for S-35
Swab wounds and sample dressings	Use swabs or syringes	
Internal contamination		
Sample	**How obtained**	**Comments**
Urine – 24-hour specimen x 4 days	Use 24 hour urine container	Take care not to contaminate sample while collecting sample
Feces – 24-hr specimen x 4 days		
Quick nasal or oral count	Use Geiger probe or swabs in nostrils or mouth	High counts could indicate S-35 inhalation

Radiological Triage

S-35 is not likely to produce life-endangering radiation dose to patients

1. External (skin and clothing) contamination only – patients are in no danger from radiation injury
2. Internal (lung) contamination – patients may receive high dose; quantify internal dose and admit if needed
3. Radiation dose < 100 rem (whole body) – do not admit unless non-radiological factors necessitate
4. Radiation dose < 800 rem (whole body) – possible immune suppression – admit and treat with antibiotics
5. Radiation dose >1000 rem (whole body) – lethal exposure – sedate and make comfortable

Radiation Fact Sheet: S-35 Contamination

Radiation Fact Sheet: Sr-90 Contamination

Overview

Sr-90 is a common isotope used for isotopic power generation and in industrial gauges. Sr-90 is typically present as a ceramic solid that presents an **external radiation hazard**. Sr-90 is almost invariably found as sealed radioactive sources that range in activity from insignificant to extremely dangerous. When in doubt, stray sources should be considered dangerous until proven otherwise. Radioactive sealed sources are usually relatively small, but RTG sources can be too large to comfortably carry. Sr-90 sources or fragments from these sources **should not be handled with bare hands**. Sr-90 sources may be used in their entirety to cause radiation sickness, or they may be ground into a fine powder to spread contamination. Although a beta emitter, Sr-90 sources can still emit dangerously high levels of x-ray radiation, and it is always found with its Y-90 progeny, which emit both beta and gamma radiation.

Medical personnel – risks and precautions

1. Sr-90 ***contamination*** poses no external radiation hazard to medical personnel
2. Medical personnel should take **Universal Precautions** when working with patients
3. Consider wearing respiratory protection (N-95 masks) if patients are heavily contaminated
4. Take routine contamination control precautions (see appropriate fact sheet)
5. High-activity Sr-90 sources have caused severe radiation injury in several incidents; such sources must be considered extremely dangerous and should not be brought into the medical center

Risks to patients

1. Inhaled Sr-90 contamination can give high radiation dose to lungs, bone, and marrow
2. Ingested Sr-90 can give high radiation dose to intestines, bone, and marrow
3. Distributed Sr-90 contamination on skin is not dangerous, although “hot” particles can give very high dose locally, in area of particle
4. Sr-90 that is absorbed through open wounds or burns is not normally a high risk to patients

Biokinetics and target organs

1. About 20-30% of ingested Sr goes to the blood, and about 60-90% of inhaled Sr goes to the blood
2. Once in the blood, 70-90% of Sr goes to the mineral portions of the bone, replacing calcium
3. Sr in the bone is eliminated with a biological half-life of about 9-10 years
4. Sr-90 in the body of a pregnant woman can be transferred to the fetus and incorporated into the fetal skeleton
5. Sr-90 can enter the milk of breast-feeding mothers

Decorporation agents

Intravenous calcium gluconate, 5x 500 mg capsules with 0.5 liters of water daily for 6 days
Speeding transit time through the intestines (via a laxative) reduces the uptake of ingested Sr

Physical data

Half-life	29.1 years	**Emissions**	Beta (546, 2284 keV)
Dose rate	0.487 rem/hr at 1 meter from 1 Curie (from Y-90)	(includes Y-90)	Gamma (480 keV)

(values include contribution of Y-90m and Y-90 progeny nuclides in equilibrium)

Radiation Fact Sheet: Sr-90 Contamination

Radiation Fact Sheet: Sr-90 Contamination

Contaminated patients

Actions			
Contamination levels (patient)	**Patient in danger of losing life, limb, or sight**	**Moderate injuries**	**Light injuries**
Heavy (>100,000 cpm)	1. Treat life-threatening injuries 2. Take staff contamination control measures 3. Control patient contamination if it does not interfere with health 4. Decontaminate patient after treatment complete	1. Decontaminate in field 2. Remove clothing or wrap in blanket or sheets 3. Take staff contamination control measures 4. Treat injuries	1. Decontaminate patient in field or in decon area 2. Remove and replace patient clothing 3. Survey skin with Geiger counter 4. Decontaminate skin 5. Treat injuries
Moderate (10,000–100,000 cpm)			
Light (<10,000 cpm)		1. Care for most serious injuries first 2. Take staff contamination control measures	

Samples

All radiation cases		
Sample	**How obtained**	**Comments**
CBC and differential	Draw from non-contaminated area	Routine sample analysis procedures
Routine urinalysis	Do not contaminate sample	
Absolute lymphocytes every 6 hrs x 8	Draw from non-contaminated area	
External contamination only		
Sample	**How obtained**	**Comments**
Swab orifices	Use moistened swabs	Count with Geiger counter or liquid scintillation counter (high-energy counting window)
Swab wounds and sample dressings	Use swabs or syringes	
Internal contamination		
Sample	**How obtained**	**Comments**
Urine – 24-hour specimen x 4 days	Use 24 hour urine container	Take care not to contaminate sample while collecting sample
Feces – 24-hr specimen x 4 days		
Nasal or oral swabs	Use moistened swabs, count with Geiger counter or use liquid scintillation counter (high-energy counting window)	High counts could indicate inhalation of Sr-90

Radiological Triage

1. External (skin and clothing) contamination only – patients are in no danger from radiation injury
2. Internal (lung) contamination – patients may receive high dose; quantify internal dose and admit if needed
3. Radiation dose < 100 rem (whole body) – do not admit unless non-radiological factors necessitate
4. Radiation dose < 800 rem (whole body) – possible immune suppression – admit and treat with antibiotics
5. Radiation dose >1000 rem (whole body) – lethal exposure – sedate and make comfortable

Radiation Fact Sheet: Sr-90 Contamination

Radiation Fact Sheet: I-131 Contamination

Overview

I-131 is a common isotope used in nuclear medicine for both diagnosis and therapy. I-131 is typically present as a colorless liquid that presents an **internal and external radiation hazard**. Medical I-131 is almost invariably found in vials or syringes that pose a moderate risk. I-131 vials and syringes **should not be handled with bare hands**. I-131 liquid should be treated with caution because it is easily absorbed through the skin and can give a high dose of radiation to the thyroid. I-131 is also released in nuclear explosions and major nuclear reactor accidents Patients with an uptake of I-131 will "shed" the isotope in their urine, feces, perspiration, and other bodily fluids, making them a risk for spreading contamination even after external decontamination is conducted.

Medical personnel – risks and precautions

1. I-131 ***contamination*** poses no external radiation hazard to medical personnel
2. Medical personnel should take **Universal Precautions** when working with patients (in particular, avoid direct skin contact and contact with excreta and bodily fluids)
3. Consider wearing respiratory protection (N-95 masks) if patients are heavily contaminated
4. Take routine contamination control precautions (see appropriate fact sheet)

Risks to patients

1. Inhaled and ingested I-131 can cause high radiation dose to the thyroid
2. I-131 is easily absorbed through the skin and, when internalized, goes to the thyroid
3. 1 µCi of I-131 in the thyroid produces about 1 rem of thyroid radiation dose
4. The thyroid is more sensitive to the effects of radiation than other organs, so I-131 uptake (ingestion, inhalation, absorption) poses little risk to the patient, even if thyroid dose may be elevated

Biokinetics and target organs

1. Nearly 100% of I-131 is absorbed through the lungs, GI tract, or open wounds
2. 30% of I-131 entering the blood goes to the thyroid
3. 70% of I-131 entering the blood is excreted within 1-2 days of uptake
4. I-131 entering the thyroid is retained with a biological half-life of 80 days
5. I-131 exits the body primarily in the feces and urine

Thyroid blocking agents

Administration of potassium iodide (KI) within 3 hours of exposure to I-131 can reduce I-131 uptake and reduce thyroid dose. KI will ONLY have an affect with patients exposed to iodine, not to any other elements.

FDA recommendations (2001)

Age	Dose (mg)	Age	Dose (mg)
Birth – 1 month	16	12 – 17 years	65
1 month – 3 years	32	18 – 40 years	130
4 – 11 years	65	40+ years	130

Breast-feeding women should take 130 mg of KI

Physical data

Half-life	8.0 days	**Emissions**	Beta (606 keV)
Dose rate	0.22 rem/hr at 1 meter from 1 Curie		Gamma (365 keV)

Radiation Fact Sheet: I-131 Contamination

Radiation Fact Sheet: I-131 Contamination

Contaminated patients

Actions			
Contamination levels (patient)	**Patient in danger of losing life, limb, or sight**	**Moderate injuries**	**Light injuries**
Heavy (>100,000 cpm)	1. Treat life-threatening injuries 2. Take staff contamination control measures 3. Control patient contamination if it does not interfere with health 4. Decontaminate patient after treatment complete	1. Decontaminate in field 2. Remove clothing or wrap in blanket or sheets 3. Take staff contamination control measures 4. Treat injuries	1. Decontaminate patient in field or in decon area 2. Remove and replace patient clothing 3. Survey skin with Geiger counter or NaI gamma scintillation detector 4. Decontaminate skin 5. Treat injuries
Moderate (10,000–100,000 cpm)			
Light (<10,000 cpm)		1. Care for most serious injuries first 2. Take staff contamination control measures	

Samples

All radiation cases		
Sample	**How obtained**	**Comments**
CBC and differential	Draw from non-contaminated area	Routine sample analysis procedures
Routine urinalysis	Do not contaminate sample	
Absolute lymphocytes every 6 hrs x 8	Draw from non-contaminated area	
External contamination only		
Sample	**How obtained**	**Comments**
Swab orifices	Use moistened swabs	Count with Geiger or NaI gamma probe, or count in gamma counter set for I-131
Swab wounds and sample dressings	Use swabs or syringes	
Internal contamination		
Sample	**How obtained**	**Comments**
Urine – 24-hour specimen x 4 days	Use 24 hour urine container	Take care not to contaminate sample during collection
Feces – 24-hr specimen x 4 days		
Thyroid bioassay (hold NaI scintillation detector over thyroid and compare count rate to background – see instrument use fact sheet and Radiological Primer)	Use NaI scintillation detector on contact with chest, over lungs; or borrow Nuclear Medicine gamma counter	High counts could indicate uptake of I-131

Radiological Triage

1. External (skin and clothing) contamination only – patients are in no danger from radiation injury
2. Internal (lung) contamination – patients may receive high dose; quantify internal dose and admit if needed
3. Radiation dose < 100 rem (whole body) – do not admit unless non-radiological factors necessitate
4. Radiation dose < 800 rem (whole body) – possible immune suppression – admit and treat with antibiotics
5. Radiation dose >1000 rem (whole body) – lethal exposure – sedate and make comfortable

Radiation Fact Sheet: I-131 Contamination

Radiation Fact Sheet: Co-60 Contamination

Overview

Co-60 is a common isotope used for medical therapy, industrial process control gauges, research and industrial irradiators, and industrial radiography. Co-60 is often present as a metallic alloy that is not easily dispersible. However, it is also possible to dissolve Co-60 or to grind an alloy source, making it a potential inhalation or ingestion hazard. Co-60 is almost invariably found as sealed radioactive sources that range in activity from insignificant to extremely dangerous. When in doubt, stray sources should be considered dangerous until proven otherwise. To avoid potentially serious radiation burns, Co-60 sources **should not be handled with bare hands**.

Medical personnel – risks and precautions

1. Co-60 contamination poses no external radiation hazard to medical personnel
2. Medical personnel should take **Universal Precautions** when working with patients
3. Consider wearing respiratory protection (N-95 masks) if patients are heavily contaminated
4. Take routine contamination control precautions (see appropriate fact sheet)

Risks to patients

1. Inhaled Co-60 contamination can give high radiation dose to lungs
2. Ingested insoluble Co-60 can give high radiation dose to the intestinal tract, while soluble Co-60 distributes fairly evenly through the body
3. Distributed Co-60 contamination on skin is not dangerous, although "hot" particles can give very high dose locally, in area of particle
4. Co-60 that is absorbed through open wounds or burns is not normally a high risk to patients

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Biokinetics and target organs

1. No more than 30% of ingested or inhaled Co-60 enters the blood
2. 50% of Co-60 that enters the blood goes directly to be excreted
3. 45% of Co-60 that enters the blood is evenly distributed through the body
4. 60% of Co-60 that goes to tissues is excreted with a biological half-life of 6 days
5. 20% of Co-60 is excreted with a half-life of 60 days and 20% with a half-life of 600 days
6. Co-60 is primarily excreted through the feces

Decorporation agents

1. No decorporation agents have been approved
2. May consider using oral penicillamine

Physical data

Half-life	5.27 years	**Emissions**	Beta (318 keV)
Dose rate	1.13 rem/hr at 1 meter from 1 Curie		Gamma (1.17, 1.33 MeV)

Radiation Fact Sheet: Co-60 Contamination

Radiation Fact Sheet: Co-60 Contamination

Contaminated patients

Actions			
Contamination levels (patient)	**Patient in danger of losing life, limb, or sight**	**Moderate injuries**	**Light injuries**
Heavy (>100,000 cpm)	1. Treat life-threatening injuries 2. Take staff contamination control measures 3. Control patient contamination if it does not interfere with health 4. Decontaminate patient after treatment complete	1. Decontaminate in field 2. Remove clothing or wrap in blanket or sheets 3. Take staff contamination control measures 4. Treat injuries	1. Decontaminate patient in field or in decon area 2. Remove and replace patient clothing 3. Survey skin with Geiger counter or NaI gamma scintillation detector 4. Decontaminate skin 5. Treat injuries
Moderate (10,000–100,000 cpm)			
Light (<10,000 cpm)		1. Care for most serious injuries first 2. Take staff contamination control measures	

Samples

All radiation cases		
Sample	**How obtained**	**Comments**
CBC and differential	Draw from non-contaminated area	Routine sample analysis procedures
Routine urinalysis	Do not contaminate sample	
Absolute lymphocytes every 6 hrs x 8	Draw from non-contaminated area	
External contamination only		
Sample	**How obtained**	**Comments**
Swab orifices	Use moistened swabs	Count with Geiger or NaI gamma probe, or count in gamma counter set for Co-60
Swab wounds and sample dressings	Use swabs or syringes	
Internal contamination		
Sample	**How obtained**	**Comments**
Urine – 24-hour specimen x 4 days	Use 24 hour urine container	Take care not to contaminate sample while collecting sample
Feces – 24-hr specimen x 4 days		
Quick chest count	Use Geiger or NaI scintillation detector on contact with chest, over lungs	High counts could indicate Co-60 inhalation

Radiological Triage

1. External (skin and clothing) contamination only – patients are in no danger from radiation injury
2. Internal (lung) contamination – patients may receive high dose; quantify internal dose and admit if needed
3. Radiation dose < 100 rem (whole body) – do not admit unless non-radiological factors necessitate
4. Radiation dose < 800 rem (whole body) – possible immune suppression – admit and treat with antibiotics
5. Radiation dose >1000 rem (whole body) – lethal exposure – sedate and make comfortable

Radiation Fact Sheet: Co-60 Contamination

Radiation Fact Sheet: Cs-137 Contamination

Overview

Cs-137 is a common isotope used for medical therapy, industrial process control gauges, research and industrial irradiators, and in gauges used in measuring soil properties. Cs-137 is often present as easily dispersible CsCl powder that can cause contamination and that presents an **inhalation hazard**. Cs-137 is almost invariably found as sealed radioactive sources that range in activity from insignificant to potentially dangerous. When in doubt, stray sources should be considered dangerous until proven otherwise. Cs-137 sources or the powder from these sources (often described as being a "pretty blue" color) **should not be handled with bare hands**.

Medical personnel – risks and precautions

1. Cs-137 contamination poses no external radiation hazard to medical personnel
2. Medical personnel should take **Universal Precautions** when working with patients
3. Consider wearing respiratory protection (N-95 masks) if patients are heavily contaminated
4. Take routine contamination control precautions (see appropriate fact sheet)

Risks to patients

1. Inhaled Cs-137 contamination can give high radiation dose to lungs
2. Ingested Cs-137 can give high radiation dose to intestines
3. Distributed Cs-137 contamination on skin is not dangerous, although "hot" particles can give very high dose locally, in area of particle
4. Cs-137 that is absorbed through open wounds or burns is not normally a high risk to patients

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Biokinetics and target organs

1. Completely absorbed through lungs, GI tract, and open wounds
2. Follows potassium in body
3. 90% of Cs-137 that enters the blood remains with a biological half-life of 110 days
4. 10% of Cs-137 that enters the blood remains with a biological half-life of 2 days
5. Cs-137 that enters the distributes fairly equally to all internal organs – there is no target organ
6. Cs-137 exits the body primarily in the urine and feces

Decorporation agents

1. Prussian Blue (ferric ferrocyanate) – 1 gram orally 3 times daily for 2-3 weeks
2. Ion exchange resins

Physical data

Half-life	30.17 years	**Emissions**	Beta (365 keV)
Dose rate	0.332 rem/hr at 1 meter from 1 Curie		Gamma (662 keV)

Radiation Fact Sheet: Cs-137 Contamination

Radiation Fact Sheet: Cs-137 Contamination

Contaminated patients

Actions			
Contamination levels (patient)	**Patient in danger of losing life, limb, or sight**	**Moderate injuries**	**Light injuries**
Heavy (>100,000 cpm)	1. Treat life-threatening injuries 2. Take staff contamination control measures 3. Control patient contamination if it does not interfere with health 4. Decontaminate patient after treatment complete	1. Decontaminate in field 2. Remove clothing or wrap in blanket or sheets 3. Take staff contamination control measures 4. Treat injuries	1. Decontaminate patient in field or in decon area 2. Remove and replace patient clothing 3. Survey skin with Geiger counter or NaI gamma scintillation detector 4. Decontaminate skin 5. Treat injuries
Moderate (10,000–100,000 cpm)			
Light (<10,000 cpm)		1. Care for most serious injuries first 2. Take staff contamination control measures	

Samples

All radiation cases		
Sample	**How obtained**	**Comments**
CBC and differential	Draw from non-contaminated area	Routine sample analysis procedures
Routine urinalysis	Do not contaminate sample	
Absolute lymphocytes every 6 hrs x 8	Draw from non-contaminated area	
External contamination only		
Sample	**How obtained**	**Comments**
Swab orifices	Use moistened swabs	Count with Geiger or NaI gamma probe, or count in gamma counter set for Cs-137
Swab wounds and sample dressings	Use swabs or syringes	
Internal contamination		
Sample	**How obtained**	**Comments**
Urine – 24-hour specimen x 4 days	Use 24 hour urine container	Take care not to contaminate sample while collecting sample
Feces – 24-hr specimen x 4 days		
Quick chest count	Use Geiger or NaI scintillation detector on contact with chest, over lungs	High counts could indicate Cs-137 inhalation

Radiological Triage

1. External (skin and clothing) contamination only – patients are in no danger from radiation injury
2. Internal (lung) contamination – patients may receive high dose; quantify internal dose and admit if needed
3. Radiation dose < 100 rem (whole body) – do not admit unless non-radiological factors necessitate
4. Radiation dose < 800 rem (whole body) – possible immune suppression – admit and treat with antibiotics
5. Radiation dose >1000 rem (whole body) – lethal exposure – sedate and make comfortable

Radiation Fact Sheet: Cs-137 Contamination

Radiation Fact Sheet: Ir-192 Contamination

Overview

Ir-192 is a common isotope used for medical therapy, and industrial radiography. Ir-192 is typically present as a metallic alloy that presents an **external radiation hazard**. Ir-192 is almost invariably found as sealed radioactive sources that range in activity from insignificant to potentially dangerous. When in doubt, stray sources should be considered dangerous until proven otherwise. Radioactive sealed sources are usually relatively small metallic cylinders (usually 1 mm or less in diameter and a few mm long). Ir-192 sources or fragments from these sources **should not be handled with bare hands**. Ir-192 sources may be used in their entirety to cause radiation sickness, or they may be ground into a fine powder to spread contamination

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Medical personnel – risks and precautions

1. Ir-192 ***contamination*** poses no external radiation hazard to medical personnel
2. Medical personnel should take **Universal Precautions** when working with patients
3. Consider wearing respiratory protection (N-95 masks) if patients are heavily contaminated
4. Take routine contamination control precautions (see appropriate fact sheet)

Risks to patients

1. Inhaled Ir-192 contamination can give high radiation dose to lungs
2. Ingested Ir-192 can give high radiation dose to intestines
3. Distributed Ir-192 contamination on skin is not dangerous, although "hot" particles can give very high dose locally, in area of particle
4. Ir-192 that is absorbed through open wounds or burns is not normally a high risk to patients

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Biokinetics and target organs

1. Only a small fraction of Ir-192 is absorbed through the lungs, GI tract, or open wounds
2. 54% of Ir-192 entering the blood is evenly distributed to all tissues
3. 20% of Ir-192 entering the blood goes to the liver
4. 80% of Ir-192 entering any tissue is retained with a biological half-life of 200 days
5. Ir-192 exits the body primarily in the feces

Decorporation agents

1. No decorporation agents are FDA-approved
2. Oral penicillamine suggested by Marcus et al. – not FDA-approved and not suggested for patients with penicillin allergies

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Physical data

Half-life	74 days	**Emissions**	Beta (675, 539 keV)
Dose rate	1.29 rem/hr at 1 meter from 1 Curie		Gamma (317, 468, 309 keV)

Radiation Fact Sheet: Ir-192 Contamination

Radiation Fact Sheet: Ir-192 Contamination

Contaminated patients

Actions			
Contamination levels (patient)	**Patient in danger of losing life, limb, or sight**	**Moderate injuries**	**Light injuries**
Heavy (>100,000 cpm)	1. Treat life-threatening injuries 2. Take staff contamination control measures 3. Control patient contamination if it does not interfere with health 4. Decontaminate patient after treatment complete	1. Decontaminate in field 2. Remove clothing or wrap in blanket or sheets 3. Take staff contamination control measures 4. Treat injuries	1. Decontaminate patient in field or in decon area 2. Remove and replace patient clothing 3. Survey skin with Geiger counter or NaI gamma scintillation detector 4. Decontaminate skin 5. Treat injuries
Moderate (10,000–100,000 cpm)			
Light (<10,000 cpm)		1. Care for most serious injuries first 2. Take staff contamination control measures	

Samples

All radiation cases		
Sample	**How obtained**	**Comments**
CBC and differential	Draw from non-contaminated area	Routine sample analysis procedures
Routine urinalysis	Do not contaminate sample	
Absolute lymphocytes every 6 hrs x 8	Draw from non-contaminated area	
External contamination only		
Sample	**How obtained**	**Comments**
Swab orifices	Use moistened swabs	Count with Geiger or NaI gamma probe, or count in gamma counter set for Ir-192
Swab wounds and sample dressings	Use swabs or syringes	
Internal contamination		
Sample	**How obtained**	**Comments**
Urine – 24-hour specimen x 4 days	Use 24 hour urine container	Take care not to contaminate sample while collecting sample
Feces – 24-hr specimen x 4 days		
Quick chest count	Use Geiger or NaI scintillation detector on contact with chest, over lungs	High counts could indicate inhalation of Ir-192

Radiological Triage

1. External (skin and clothing) contamination only – patients are in no danger from radiation injury
2. Internal (lung) contamination – patients may receive high dose; quantify internal dose and admit if needed
3. Radiation dose < 100 rem (whole body) – do not admit unless non-radiological factors necessitate
4. Radiation dose < 800 rem (whole body) – possible immune suppression – admit and treat with antibiotics
5. Radiation dose >1000 rem (whole body) – lethal exposure – sedate and make comfortable

Radiation Fact Sheet: Ir-192 Contamination

Radiological fact sheet: Radiation units and terminology

Radiation units

Curie (Ci) A unit of radioactivity that measures the rate at which radiation is emitted from radioactive materials. Radiation levels and risk are related to the number of Curies present. In general, sources that are less than a few tens of Curies will not emit dangerous levels of radiation. The international unit is the Becquerel (abbreviated Bq); sources that are less than a few billion Bq (a few GBq) do not emit dangerous amounts of radiation.

Rad A unit of radiation dose that measures the amount of energy from radiation you have absorbed. In general, a dose of about 100 rad will begin to cause radiation sickness and doses of several hundred rads may be lethal. The international unit is the Gray (Gy); 1 Gy is equal to 100 rad.

Rem A unit of radiation dose that accounts for the different biological effects of various kinds of radiation. Radiation workers are limited to 5 rem annually from normal work and are allowed to receive up to 25 rem in emergency situations. To save lives, there are no limits given, but some organizations recommend 50 rem. The international unit is the Sievert (Sv); 1 Sv is equal to 100 rem.

Terminology

Radiation Radiation is energy that is given off by unstable atoms. The energy comes out in the form of gamma rays, alpha particles, and beta particles. Radiation is emitted from radioactive materials – it is one of their properties, along with color, size, and weight.

Contamination
The presence of radioactivity in an area or on something that is not normally radioactive. In a dirty bomb attack, radioactive contamination would be spread over streets, sidewalks, or buildings that would need to be cleaned up. It is possible to have high levels of contamination that do not produce high levels of radiation because contamination measures only the amount of radioactivity present and not the damage caused by that radiation. Contamination is measured in units of counts per minute (cpm) using a Geiger counter or similar instrument.

Alpha Alpha radiation consists of particles (on an atomic level) that are emitted by heavy atoms such as uranium, radium, or lead. Alpha radiation is not a hazard unless it is inhaled, ingested, or enters the body through open cuts or scrapes. However, if it does enter the body, it is the most damaging form of radiation. If you are working in the presence of alpha contamination, you must take precautions to avoid inhaling or ingesting any alpha radioactivity, and any open wounds should be bandaged if at all possible.

Radiological fact sheet: Radiation units and terminology

Radiological fact sheet: Radiation units and terminology

Beta Beta radiation consists of particles, although they are smaller than alpha particles. Any element can emit beta radiation. Beta radiation will only penetrate up to a half inch in human tissue, so it will not expose internal organs unless it is ingested or inhaled. Some beta-emitting radioactive materials can be absorbed through the skin; beta radioactivity can also enter the body by ingestion, inhalation, or through open wounds. Beta radiation is much less damaging than alpha radiation, but drops of beta radioactivity can cause localized skin burns under some circumstances. If you are working in the presence of beta radiation, you should take precautions to avoid ingesting or inhaling radioactivity, and you should wear protective clothing (see the PPE fact sheet) to avoid having beta contamination on your bare skin.

Gamma Gamma radiation consists of rays that are similar to x-rays or light rays. Any element can emit gamma radiation. Gamma rays will penetrate through the entire body, just like x-rays, so external gamma radiation will cause radiation dose to internal organs. However, gamma radiation is much less damaging than alpha radiation. Some gamma-emitting isotopes are absorbed through the skin, and it is also possible for gamma-emitting radioactivity to be ingested or inhaled. If you are working in the presence of gamma radiation, you should take precautions to avoid inhaling or ingesting radioactivity and you should wear protective clothing to avoid having gamma contamination on your skin.

Half life The amount of time it takes for one half of an amount of radioactivity to decay away. For example, the half-life of I-131 is 8 days, so a 1 Ci I-131 source will have only 0.5 Ci after 8 days, 0.25 Ci after 16 days, and 0.125 Ci after 24 days. After each half-life, the amount of radioactivity remaining drops by a further factor of 2.

Radiological fact sheet: Radiation units and terminology

Radiological Fact Sheet: Controlling contamination

Risks Contamination (measured in counts per minute) measures number of "bits" of radiation that come from a given area, and each of these bits (counts) does only a tiny amount of damage. ***So even a very high level of contamination on the skin emits only a little amount of radiation, and poses very little risk.*** However, contamination that enters the body (especially inhaled) can be more dangerous and should be avoided. Working with radioactive contamination is like changing a dirty diaper – the contamination won't kill you, but you still want avoid getting it on you if you can.

Ambulance and treatment area contamination control

1. Wrap patient in blankets to contain contamination and reduce contamination of facilities
2. Establish dedicated routes for transporting contaminated patients
3. Establish dedicated areas for decontamination and contaminated victim care
4. Line dedicated routes and rooms with plastic to reduce contamination of fixed surfaces
5. Do not use vehicles or equipment for non-contaminated victims unless necessary

Contamination control actions during an emergency response

1. Wear proper PPE and respiratory protection (see the PPE fact sheet)
2. Most airborne contamination will settle in the first half hour after the event (although fires or heavy winds may suspend or re-suspend particles)
3. Walking across very heavily contaminated areas may lead to re-suspension and possible inhalation concerns
4. Leave controlled areas only at contamination control checkpoints
5. Remove PPE and conduct radiological survey upon leaving the controlled area when the victim's condition permits

Working with contaminated victims

1. **Treat life-threatening injuries first**.
2. Try to avoid getting contamination into open wounds
    a. Rinse with saline, de-ionized water, clean with alcohol wipes if possible
3. If time permits, wrap heavily contaminated persons in sheets or blankets
4. If time permits, remove victim's clothing or dress in coveralls or "bunny suit"
5. When possible, wear appropriate PPE when treating victims
    a. Surgical gloves, N95 mask or equivalent, shoe covers, and coveralls
6. Use disposable equipment (blood pressure cuffs, for example) when possible
7. Assume that all equipment used on a victim is radioactively contaminated
    a. Decontaminate before using with another victim if possible
    b. Use without decontamination if necessary to save a life

Radiological Fact Sheet: Controlling contamination

Radiological Fact Sheet: Controlling contamination

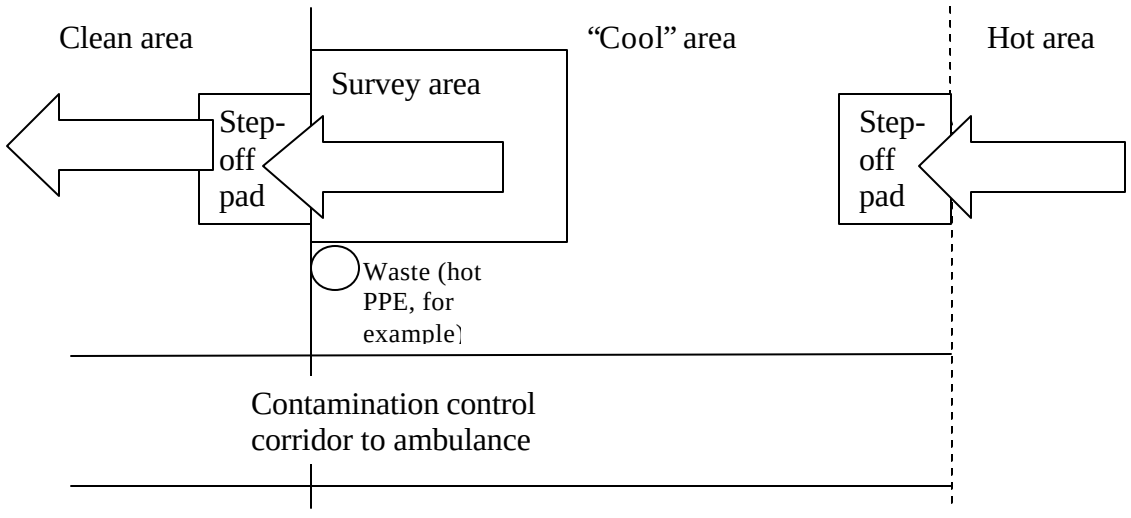
Leaving a controlled area - victim

(Items in bold ***must*** be performed, others ***should*** be followed when time and personnel permit)

1. **Enter "hot" side of exit point**
2. Log names of responder and victim
3. Transfer victim to "clean" stretcher OR survey and decontaminate stretcher
    a. Refer to survey and decontamination fact sheets
    b. If possible, wrap victim in clean sheets or blankets prior to transfer
4. **Transfer victim to hospital or field facility for further medical care**
5. Perform contamination survey of exit point and the transfer route when ambulance leaves
6. Prepare for next victim

Leaving a controlled area – responders

1. **Enter "hot" side of exit point**
2. Log name of responder entering the exit point
3. **Survey outer gloves or hands for contamination**
4. **Survey coveralls or outer clothing for radioactive contamination**
    a. If contaminated, remove coveralls or outer clothing and place in radioactive waste container or plastic bag
5. Step to "cold" boundary of exit point
6. **Remove shoe covers while stepping over boundary to "cold" side of exit point**
7. **Remove gloves inside out and place into radioactive waste container or plastic bag**
8. Survey whole body, concentrating on hands, feet, face, knees, elbows, and seat of pants
9. Survey exit point and step-off pad(s) periodically and decontaminate as necessary



Radiological Fact Sheet: Controlling contamination

Radiological Fact Sheet: Radiological Decontamination

Decontamination

If there is a radiological attack or incident, you may be working in a contaminated area or taking care of contaminated victims. This is probably going to cause you to become contaminated. Contamination can be reduced by wearing proper PPE (see the PPE fact sheet). But you might still need to decontaminate yourself, a victim, or your equipment.

Decontaminating yourself (after performing a whole-body survey to locate contamination) – take those steps that are possible with available materials

1. Remove contaminated clothing and place into radioactive waste container
2. Survey beneath contaminated areas on clothing
3. If skin is contaminated, immediately notify health and safety personnel
4. If multiple areas are contaminated, decontaminate areas with open cuts or wounds first, body orifices (e.g. mouth, nose) next, and contaminated skin beginning with the most-contaminated
5. Flush contaminated areas with saline or clean water
6. Wash with mild soap and cool to warm water
    a. Large areas of contaminated skin may require a shower
7. Monitor every few washes to confirm that counts are dropping – if so, it means that the decontamination is working
8. If these decontamination efforts are not effective, sealing the contaminated area in a plastic bag or wrap for several hours is often effective (not recommended with facial contamination)
9. If this does not reduce contamination levels, request assistance from radiation safety personnel
10. Collect liquids, rags, wipes as radioactive waste in containers or bags marked to contain radioactive waste

Victim decontamination

1. Remove patient's clothing, if possible (weather, time, victim's condition, etc. may make this impossible
2. Rinse contaminated areas with saline solution or de-ionized water
3. Shower or bathe patient, using mild soap and cool to warm water
4. Give sponge bath, discard sponge or washcloth as radioactive waste
5. Flush open wounds with saline solution or de-ionized water
6. Use standard sterile practices prior to administering injections, suturing, or other practices that puncture or break the skin

Radiological Fact Sheet: Radiological Decontamination

Decontaminating equipment

1. Smooth surfaces (glass, plastic, metal) can be decontaminated by washing or wiping as described below
2. Begin by wiping with rag or cloth dampened with water or alcohol
3. If still contaminated after several attempts, try wiping with a commercial product (window cleaner, oven cleaner, etc.)
4. Another technique is to use tape to remove loose contamination by pressing the sticky side of the tape to contaminated areas
5. If still contaminated, try wiping with specialty product such as Radiac Wash, IsoClean, or Counts Off or with a chelating agent such as EDTA
6. If still contaminated, contamination is probably fixed in the object; if less than 5,000 counts per minute above background, may continue to use

7. Porous surfaces (wood, cloth, some ceramics, etc.) cannot be decontaminated by washing or wiping
8. Begin with pressing tape to contaminated areas
9. Wipe with water, alcohol, and other agents as noted above
10. If this is unsuccessful, item may be soaked in a cleaning solution or placed in an ultrasonic sink
11. As a last resort soft items (wood, plastic, lead, etc.) may be shaved with a sharp knife to remove contaminated areas. Contaminated sections of fabric or paper can be cut out and the remainder used.

12. If contamination is fixed in equipment (such as stretcher coverings), and the equipment must be used, cover the contaminated area with plastic or clean cloth and continue using the equipment as long as necessary
13. Large areas (such as ambulance interiors, vehicle exteriors) may be decontaminated by wiping with a sponge or rags soaked in soapy water, detergent, or other cleaning solutions

14. **All waste should be placed into containers marked as radioactive and, if possible, marked with the radiation symbol**

Radiation Fact Sheet: PPE and Respiratory Protection

Need for PPE: In the event of a large event involving radiation or radioactivity (such as a terrorist attack or nuclear power plant accident) there will be a large number of emergency responders working in contaminated areas as they rescue victims, fight fires, and so forth. Although radioactive contamination does not normally present a serious health risk, proper PPE are important to minimize the amount of skin contamination or radioactive materials uptake.

PPE Inspection: ***Prior to donning PPE, they should be inspected as described below***

1. Check coveralls for rips, tears, or split seams
2. Check gloves for holes or split seams
3. Check shoe covers and booties for holes and for proper size
4. Verify proper operation of respiratory protection
    a. Ensure nuisance masks or N-95 filters do not have holes
    b. Ensure all masks fit tightly around nose and chin
    c. Confirm sufficient air supply in forced air masks
    d. Check all hoses for holes
5. Remove watches, jewelry, rings, etc.

Levels of PPE

Level D:	Gloves Booties or shoe covers	***Level D+***	Level 1 PPE Coveralls
Level C:	Level 2 PPE Inner gloves Outer shoe covers Head covering (if required)	***Level B:***	Level 3 PPE Tape openings Respiratory protection

Donning PPE

1. Turnout gear or coveralls
2. Shoe covers (tape at ankles if necessary and possible)
3. Gloves (tape inner gloves at wrists if necessary)
4. Hood or head covering (if applicable)
5. Respiratory protection (if necessary)
6. Dosimeter (should be easily accessible)

Doffing PPE

1. Remove outer gloves
2. Give dosimeter to H & S
3. Remove tape at ankles and wrists
4. Coveralls (turnout coat and pants)
5. Head cover, helmet, and/or hood
6. Shoe covers (step to “clean” area)
7. Inner gloves

After PPE are removed:

1. Perform whole-body contamination survey, in accordance with radiological survey fact sheet
2. Place contaminated PPE and clothing into designated radioactive waste receptacles
3. Wash hands and face, shower if possible

Radiation Fact Sheet: PPE and Respiratory Protection

Radiation Fact Sheet: PPE and Respiratory Protection

Incident	Radiological concerns	Appropriate PPE	
		Emergency phase	**Recovery phase**
"Dirty bomb" or Radioactive fire	1. "hot particles" on skin 2. inhaling radioactivity 3. swallowing radioactive materials	1. turnout gear (gloves, boots, coat) 2. full-face air-purifying respirator or forced air 3. personal dosimetry	1. coveralls (plastic, cloth, disposable) 2. gloves (rubber, leather, surgical) 3. shoe covers (boots, booties, etc.) 4. nuisance mask for dust 5. personal dosimetry
Irradiation device	1. high radiation levels and radiation sickness	1. electronic personal alarming dosimeter	1. electronic personal alarming dosimeter
Airborne spray	1. skin contamination 2. "hot particles" on skin 3. inhalation or ingestion of radioactive materials	1. turnout gear (gloves, boots, coat) 2. full-face air-purifying respirator or better (SCBA preferred)	1. coveralls (plastic, cloth, disposable) 2. gloves (rubber, leather, surgical) 3. shoe covers (boots, booties, etc.) 4. nuisance mask for dust (unless air sampling indicates otherwise)

Notes

1. If time and conditions permit, tape coveralls or turnout gear at wrists and ankles to reduce contamination
2. If there are not enough personal dosimeters for each person, give at least one person in each group (e.g. hose team, rescue party) a dosimeter.
3. Radioactive contamination on the ground or on a victim does not normally emit dangerously high radiation levels, although inhaling high levels of contamination may be hazardous
4. Life-saving actions (rescuing victims, fire-fighting, stabilizing structures) should be taken without regard to contamination levels, provided responders wear appropriate PPE and respiratory protection
5. When possible, perform radiation dose rate and contamination level surveys (in accordance with the radiological surveys fact sheet) at the earliest opportunity

Radiation Fact Sheet: PPE and Respiratory Protection

Radiological Fact Sheet: Radiation Health Effects

Short-term exposure to high levels of radiation

What is it?
- Exposure to enough radiation to cause radiation sickness (more than 100 rem)
- The exposure takes place too rapidly for the body to repair the damage (several hours or less)

How?
- A terrorist group places a very high-activity radioactive source in a public place
- A terrorist group launches a "dirty bomb" attack with a very high-activity radioactive source that does not disperse widely
- An emergency responder inhales high levels of alpha radioactivity

Effects
- 100 rem to the whole body can cause radiation sickness (delayed nausea and vomiting)
- 200 – 300 rem to the skin can cause skin burns
- 400 rem to the lens of the eye can cause cataracts
- 400 rem to the whole body gives a 50% risk of death without medical treatment
- 800 rem to the whole body gives a 50% risk of death with intensive medical care
- 1000 rem to the whole body gives a 100% risk of death

Protection
- Minimize the amount of time spent in a radiation area
- Stay at the greatest distance possible from areas with the highest radiation levels
- Use walls, equipment, vehicles, etc. as shielding between yourself and the radiation source
- At least one person in each group should have radiation instruments or film badges

Long-term effects following exposure to elevated levels of radiation

What is it?
- Long-term effects occur years or decades after exposure to radiation

How?
- After recovering from radiation sickness, there may be residual radiation damage to DNA
- This damage may lead, in later years, to cancer or other health problems

Effects
- Exposure to radiation may lead to cancer after a 10-30 year latency period, but the cancer risk from even a high radiation dose is not high (about 1-2 chances in 100 from 100 rem)
- Exposure to radiation before conception is not linked to birth defects or children's health risks

Protection
- Take the steps noted above to reduce radiation exposure during emergency response
- Don't panic! Radiation can cause cancer, but it is not very effective at doing so

Radiological Fact Sheet: Radiation Health Effects

Radiological Fact Sheet: Radiation Health Effects

Long-term effects from long-term exposure to low levels of radiation

What is it?
- Long-term effects are those that appear years or decades after exposure to radiation
- Long-term exposure to radiation is when you are exposed to the radiation for months or years
- Low levels of radiation are levels that are not high enough to cause radiation sickness

How?
- Working with radioactive contamination for long periods of time
- Working as a radiation worker for many years
- Living or working in an area that was contaminated and not yet cleaned up

Effects
- May cause a very small increase in cancer risk, but this risk is less than from driving to work
- Will not cause birth defects or other reproductive problems

What exposure to radiation will NOT do

1. Radiation exposure will not give you a headache
2. Radiation sickness usually does not make you ill right away (except when a person has received very high doses)
3. Radiation exposure does not register in our senses (it can't be seen, felt, heard, tasted, or smelled)
4. Radiation exposure will not cause your skin to tingle

Radiological Fact Sheet: Radiation Health Effects

Radiological Fact Sheet: Radiation Health Effects

If your whole body is exposed to a high level of radiation in a short time

25 rem	minor changes in blood cell counts show up a few weeks later
100 rem	minor radiation sickness (nausea, vomiting) a few weeks later
450 rem	lethal dose to 50% of those exposed without medical treatment
800 rem	lethal dose to 50% of those exposed with medical treatment
1000 rem	lethal dose to 100% of those exposed

How long will it take to reach 100 rem:

4 minutes or more	3 feet from a large (1000 Curies) irradiator source
15 minutes or more	6 feet from a large (1000 Curies) irradiator source
12 hours or more	On a 1 acre site contaminated with 1000 Curies from a gamma source

Condition	Skin dose in rem (see note)
Reddened skin (like sunburn)	200
Loss of hair from exposed skin	300
Peeling skin	1000
Open sores	2000
Skin inflammation	2500

Note: People exposed to large doses of beta radiation can have very high dose to the skin with no corresponding whole-body exposure. Limited exposure to radiation will cause burns on only the exposed skin.

For ***single, acute exposure***, note the time of the onset of vomiting, estimated dose range, and suggested actions.

Vomiting in ____ of accident	Estimated radiation dose	What you should do
< 10 minutes	> 800 rad	Dose potentially fatal, victim requires immediate medical care, including antibiotic support
10-30 minutes	600-800 rad	
30-60 minutes	400-600 rad	
1-2 hours	200-400 rad	Radiation not life-endangering, but prompt medical care necessary
> 2 hours after exposure	< 200 rad	Radiation sickness expected, medical care necessary but not urgent

Radiological Fact Sheet: Radiation Health Effects

Radiological Fact Sheet: Radiation Health Effects

Radiation dose (rad)	Prognosis	Medical issues
< 100	Survival certain	Usually no symptoms, possible loss of appetite
100-200	Survival probable	Mild acute radiation syndrome (ARS). Some nausea and vomiting.
200-800	Survival possible	Some fatigue with major blood complications and possible life-threatening complications. Requires major supportive therapy.
800-3000	Survival unlikely	Diarrhea, weakness, major blood complications if survival exceeds 1-2 weeks. Almost always fatal (especially for dose >1000)
>3000	Survival impossible	Shock, coma, and death in a few hours to a few days. Significant neurological syndrome indicates a lethal dose of radiation.

If part of your body is exposed to high levels of radiation in a short time

- 200+ rem to the skin will cause low-level radiation burns
- Burns become more severe as dose increases
- Radiation burns look like sunburn (reddened skin, blistering, peeling skin)
- Radiation will NOT char the skin, so charring is a sign of thermal burns



Why you should never pick up a radioactive source in your hand

- Radiation levels on contact with even low-activity sources can be very high
- Picking up a source with your hand can lead to severe radiation burns
- It can also lead to loss of your hand or fingers.

If you are exposed to low levels of radiation (less than 10 rem)

- Your risk of getting cancer may increase very slightly, or not at all
- The radiation does ***not*** increase the risk of having children with birth defects

Radiological Fact Sheet: Radiation Health Effects

Radiological Fact Sheet: Using Radiation Instruments

Identifying alpha, beta, or gamma radiation

1. Turn on the meter and look at the scale BEFORE going to the scene to see what background radiation levels are (see the other side of this fact sheet)
2. When you arrive at the scene, take radiation readings on the ground or on victims
3. If the readings are elevated, perform the following tests
    a. Put a piece of ***paper*** beneath the probe. If the meter reading drops to background, it is ***alpha*** radiation (see the fact sheet on alpha radioactivity). If the reading stays the same, go to step B
    b. Put your ***hand*** beneath the probe. If the meter reading drops to background, it is ***beta*** radiation (see the fact sheets on beta radioactivity and Sr-90). DO NOT touch the probe to avoid contaminating it. DO NOT touch the sample, to avoid contaminating your hand.
    c. If the reading stays the ***same***, you have ***gamma*** radiation (see the fact sheet on gamma radioactivity)

What the meter readings mean

1. If the **radiation level** is in excess of:
    a. 1000 r/hr are potentially lethal – leave area immediately
    b. 500 r/hr can cause severe radiation sickness – enter only to save lives or to take actions that are certain to have great benefit
    c. 100 r/hr can cause mild radiation sickness and can cause a person to exceed legal dose limits – enter only to rescue victims or to take actions to save property
    d. 10 r/hr or less will have no likely health effects, but may cause a person to exceed regulatory dose limits – monitor exposure and exit area before dose limit is reached
    e. Measure radiation levels with an ion chamber, Exploranium, or microR meter

2. If the **contamination levels** are in excess of:
    a. 500,000 counts per minute (cpm) – contamination may be resuspended; wear full anticontamination clothing (see PPE fact sheet) and respiratory protection
    b. 1500 cpm in any single location – must be decontaminated prior to release for unrestricted use
    c. 500 cpm average over large areas – must be decontaminated prior to release
    d. Measure contamination levels with a GM survey meter or with a sodium iodide probe connected to a meter with a dial that reads in CPM

How to perform a contamination survey

1. Turn on the meter, check the battery, and take the switch to the highest scale (usually x1000 or x10,000)
2. Turn on the audible response
3. Hold detector < ½ inch from the item being surveyed and move it at about 1-2 inches per second
4. Turn switch to lower scales until the meter reading is less than ¾ of the full scale
5. Record results on a survey map and note areas with high contamination levels (more than 1000 cpm)

How to perform a radiation survey

1. Turn on meter, check battery, take switch to highest setting
2. Hold detector or meter about waist height and walk slowly through area,
3. Note areas with elevated readings on survey maps

Radiological Fact Sheet: Using Radiation Instruments

Radiological Fact Sheet: Using Radiation Instruments



Sodium iodide (NaI) probe for **gamma contamination** and radiation surveys. This should be used for contamination surveys unless it is attached to a meter that has been calibrated to measure in radiation levels (this information should be noted on the instrument calibration records. **Record results in CPM.**



Geiger-Mueller (GM) "pancake" probe for **beta and gamma contamination surveys. Record results in CPM**.



Geiger-Mueller (GM) "hot dog" probe for **beta and gamma contamination** surveys. This may be used for measuring radiation levels only if the meter was calibrated for the isotope (e.g. Cs-137) present on the patient or in the room being monitored. **Record results in cpm.**



Zinc sulfide (ZnS) **alpha** scintillation probe. The window on this probe is exceptionally fragile and must be protected from accidental puncture. **Record results in cpm**.



Ion chamber. This detector is used to measure radiation levels from beta (with bottom window open) or gamma (with bottom window closed) radiation sources. **Record results in mr/hr.**

Radiological Fact Sheet: Using Radiation Instruments

Radiation Fact Sheet: Alpha-emitting radioactivity
Ra-226, Am-241, Cf-252

Greatest concern

Inhaling alpha radioactivity is extremely hazardous and even small amounts can cause significant health problems such as pulmonary fibrosis or radiation-induce pneumonia.

Radiation levels from alpha sources are low, so there is no need to evacuate injured victims, or to limit stay times on account of radiation levels

Primary hazards to emergency responders

Contamination: -Majority of contamination will likely settle within 100-200 yards of device

Radiation: -Radiation levels will be low, even from high-activity sources
-Even heavy contamination will not produce high radiation dose levels

Inhalation: -Gives very high dose to lungs if inhaled, fine powder stays in air longer

Ingestion: -Moderate risk from ingested radioactivity

Possible scenarios

"Dirty bomb" -Conventional explosives used to disperse radioactivity over wide area
-Likely to have high (but not dangerous) levels of contamination near scene
-Greatest dangers likely to be radioactivity inhalation, fires, damaged structures, and utility ruptures
-See tables on the other side of this sheet for PPE, respiratory protection, and boundary recommendations
- PPE requirements are provided on the PPE fact sheet

Irradiation device –These isotopes will not produce high radiation levels and are not suitable for making into an irradiation device

Airborne spray -Radioactive materials sprayed into air in public area (stadium, theater)
-May receive harmful radiation dose to lungs via inhalation
-Best protective actions are to wear breathing protection (particulate) and PPE (gloves, turnout gear or coveralls, shoe covers) prior to entry into area
-May wish to place respirators on victims if airborne rad levels are high

Radioactive fire -Smoke may contain radioactive particles and will spread contamination
-Greatest risk will be from fire
-Water used to extinguish fire likely to contain radioactivity from the fire
-Protective actions should include respiratory protection and PPE
-See the PPE fact sheet

Radiation Fact Sheet: Alpha-emitting radioactivity
Ra-226, Am-241, Cf-252

Radiation Fact Sheet: Alpha-emitting radioactivity
Ra-226, Am-241, Cf-252

Physical and Chemical Data

Radiological properties		Risks		Actions
Radiation type	Alpha	Direct radiation	Low	Treat serious injuries
External radiation dose rate	Very low	Inhalation	Very high	Decontaminate skin
Absorbed through skin?	No	Ingestion	High	Check for inhaled activity
Penetrating ability	None	Skin contamination	Moderate	Check for radiation burns

Boundary line recommendations

The amount of radioactivity may or may not be known. ***If the amount of radioactivity present cannot be determined, assume the incident involves a high level of radioactivity*** and respond accordingly until radiation safety personnel determine otherwise. The radiation levels noted are as would be read on a radiation dose-rate meter, whose operation is described in the Radiation Instruments fact sheet in the first section of this collection.

The greatest risk to victims, responders, and the public is from inhaling alpha radioactivity – respiratory protection must be the greatest concern when responding to any event involving these isotopes.

Dirty Bomb (Radiological Dispersal Device, or RDD)					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Moderate	1500 feet	4500/3000 feet	4500+
Medium	Mod walk	Low-Mod	500 feet	1500/800 feet	1500
Low	Mod walk	Low	150 feet	1200/600 feet	1000

Fire with radioactivity					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Moderate	1500 feet	4500/3000 feet	4500+
Medium	Rapid walk	Low-Mod	500 feet	1500/800 feet	1500
Low	Mod walk	Low	150 feet	1200/600 feet	1000

Airborne spray of radioactivity					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Mod-High	1500	3000/3000 feet	4500+
Medium	Rapid walk	Moderate	750	1500/1000 feet	1500
Low	Rapid walk	Moderate	300	1500/600 feet	1000

- A high-activity source has more than 10 Curies of activity, a medium-activity source has 1-10 Curies of activity, and a low-activity source has less than 1 Curie of activity
- A radiation safety professional will help to determine the source activity
- Alpha radiation sources are unlikely, but there may be low levels of radiation from associated gamma rays and from the spread of contamination

For an explanation of the units (Curies, mr, etc.) refer to the Units and Definitions fact sheets.

Radiation Fact Sheet: Alpha-emitting radioactivity
Ra-226, Am-241, Cf-252

Radiation Fact Sheet: Beta-emitting radioactivity
H-3, P-32, S-35

Greatest concern

P-32 can cause localized burns if it comes in direct contact with the skin for a prolonged period of time (longer than an hour). There is little concern from the other isotopes.

Primary hazards to emergency responders

Contamination: -Majority of contamination will likely settle within 100-200 yards of device

Radiation: -Radiation levels from even high-activity sources will be low
-Even heavy contamination will not produce high radiation dose levels

Inhalation: -Gives high dose to lungs if inhaled, fine powder can remain airborne longer

Ingestion: -Relatively low risk from ingested radioactivity

Possible scenarios

"Dirty bomb" -Conventional explosives used to disperse radioactivity over wide area
-Likely to have high (but not dangerous) levels of contamination near scene
-Greatest dangers likely to be fires, damaged structures, and utility ruptures
-See tables on the other side of this sheet for PPE, respiratory protection, and boundary recommendations
- PPE requirements are provided on the PPE fact sheet

Irradiation device –These isotopes will not produce high radiation levels and are not suitable for making into an irradiation device

Airborne spray -Radioactive materials sprayed into air in public area (stadium, theater)
-May receive harmful levels of exposure via inhalation, although radiation levels will not be dangerously high
-In addition to uptake concerns, must assume contamination will be present
-Best protective actions are to wear breathing protection (particulate) and PPE (gloves, turnout gear or coveralls, shoe covers) prior to entry into area
-May wish to place respirators on victims if airborne rad levels are high

Radioactive fire -Smoke may contain radioactive particles and will spread contamination
-Greatest risk will be from fire
-Water used to extinguish fire likely to contain radioactivity from the fire
-Protective actions should include respiratory protection and PPE
-See the PPE fact sheet

Radiation Fact Sheet: Beta-emitting radioactivity
H-3, P-32, S-35

Radiation Fact Sheet: Beta-emitting radioactivity
H-3, P-32, S-35

Physical and Chemical Data

Radiological properties		Risks		Actions
Radiation type	Beta	Direct radiation	Low	Treat serious injuries
External radiation dose rate	Very low	Inhalation	Low	Decontaminate skin
Absorbed through skin?	H-3 only	Ingestion	Low	Check for inhaled activity
Penetrating ability	Skin only	Skin contamination	Moderate	Check for radiation burns

Boundary line recommendations

The amount of radioactivity may or may not be known. ***If the amount of radioactivity present cannot be determined, assume the incident involves a high level of radioactivity*** and respond accordingly until radiation safety personnel determine otherwise. The radiation levels noted are as would be read on a radiation dose-rate meter, whose operation is described in the Radiation Instruments fact sheet in the first section of this collection.

Dirty Bomb (Radiological Dispersal Device, or RDD)					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Moderate	1500 feet	4500/3000 feet	4500+
Medium	Mod walk	Low-Mod	500 feet	1500/800 feet	1500
Low	Mod walk	Low	150 feet	1200/600 feet	1000

Fire with radioactivity					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Moderate	1500 feet	4500/3000 feet	4500+
Medium	Rapid walk	Low-Mod	500 feet	1500/800 feet	1500
Low	Mod walk	Low	150 feet	1200/600 feet	1000

Airborne spray of radioactivity					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Mod-High	1500	3000/3000 feet	4500+
Medium	Rapid walk	Moderate	750	1500/1000 feet	1500
Low	Rapid walk	Moderate	300	1500/600 feet	1000

- A high-activity source has more than 1000 Curies of activity, a medium-activity source has 100-1000 Curies of activity, and a low-activity source has less than 100 Curies of activity
- A radiation safety professional will help to determine the source activity
- Beta radiation sources are not likely to be used in irradiators, but high levels of beta contamination can cause measurable radiation levels downwind of a radioactivity release

For an explanation of the units (Curies, mr, etc.) refer to the Units and Definitions fact sheets.

Radiation Fact Sheet: Beta-emitting radioactivity
H-3, P-32, S-35

Radiation Fact Sheet: Gamma-emitting radioactivity
Cesium-137, Cobalt-60, Iridium-192

Greatest concern

All three isotopes can produce very high radiation levels. Cs-137 is usually present as a fine, water-soluble powder that is very easy to disperse. The other isotopes are usually in the form of insoluble pieces of metal, but may be ground into powder.

Primary risks to emergency responders

Contamination: -Majority of contamination will likely settle within 100-200 yards of device
Radiation: -High-activity sources can emit harmful levels of radiation up to 10 feet
-Even heavy contamination will not produce high radiation dose levels
Inhalation: -Gives high dose to lungs if inhaled, fine powder can remain airborne longer
Ingestion: -Relatively low risk from ingested radioactivity

Possible scenarios

"Dirty bomb" -Explosives used to disperse radioactivity over wide area
-Likely to have high (but not dangerous) levels of contamination near scene
-May have elevated airborne radioactivity several hundred yards downwind
-Greatest dangers likely to be fires, damaged structures, and utility ruptures
-Protective actions include proper PPE for work in high contamination levels

Irradiation device -High-activity source used to produce high radiation levels in public area
-Radiation levels may be dangerously high up to a few meters from source, but drop off rapidly with increasing distance
-Protective actions: reduce time, increase distance, use shielding
-Move victims from very high radiation levels (>500 rem/hr) ASAP
-Isolate source until radiation safety professionals arrive for source recovery
-DO NOT TOUCH SOURCE – MAY CAUSE RADIATION BURNS

Airborne spray -Radioactive materials sprayed into air in public area (stadium, theater)
-May receive harmful levels of exposure via inhalation, although radiation levels will not be dangerously high
-In addition to uptake concerns, must assume contamination will be present
-Best protective actions are to wear breathing protection (particulate) and PPE prior to entry into area
-May wish to place respirators on victims if airborne rad levels are high

Radioactive fire -Smoke may contain radioactive particles and will spread contamination
-Greatest risk will probably be from fire, unless the source is high activity
-Water used to extinguish fire likely to be contaminated
-Protective actions should include respiratory protection and PPE

Radiation Fact Sheet: Gamma-emitting radioactivity
Cesium-137, Cobalt-60, Iridium-192

Radiation Fact Sheet: Gamma-emitting radioactivity
Cesium-137, Cobalt-60, Iridium-192

Physical and Chemical Data

Radiological properties		Risks		Actions
Radiation type	Gamma	Direct radiation	Moderate	Treat serious injuries
Dose rate from source (Co)	High	Inhalation	Moderate	Decontaminate skin
Dose rate from source (Cs and Ir)	Moderate	Ingestion	Moderate	Check for inhaled activity
Penetrating ability	Whole body	Skin contamination	Moderate	Check for radiation burns

Boundary line recommendations

The amount of radioactivity may or may not be known. If the amount of radioactivity present cannot be determined, assume the incident involves a high level of radioactivity and respond accordingly until radiation safety personnel determine otherwise. The radiation levels noted are as would be read on a radiation dose-rate meter, whose operation is described in the appropriate fact sheet in the first section of this collection.

Dirty Bomb (Radiological Dispersal Device, or RDD)					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Moderate	1500 feet	4500/3000 feet	4500+
Medium	Mod walk	Low-Mod	500 feet	1500/800 feet	1500
Low	Mod walk	Low	150 feet	1200/600 feet	1000

Fire with radioactivity					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Moderate	1500 feet	4500/3000 feet	4500+
Medium	Rapid walk	Low-Mod	500 feet	1500/800 feet	1500
Low	Mod walk	Low	150 feet	1200/600 feet	1000

Airborne spray of radioactivity					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Mod-High	1500	3000/3000 feet	4500+
Medium	Rapid walk	Moderate	750	1500/1000 feet	1500
Low	Rapid walk	Moderate	300	1500/600 feet	1000

Irradiation device (radioactive source in public place)					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Very high	600	5000 feet	4500+
Medium	Mod walk	Mod-high	200	1500 feet	1500
Low	Mod walk	Low-mod	100	600 feet	1000

- A high-activity source has more than 1000 Curies of activity, a medium-activity source has 100-1000 Curies of activity, and a low-activity source has less than 100 Curies of activity
- A radiation safety professional will help to determine the source activity

For an explanation of the units (Curies, mr, etc.) refer to the Units and Definitions fact sheets.

Radiation Fact Sheet: Gamma-emitting radioactivity
Cesium-137, Cobalt-60, Iridium-192

Radiation Fact Sheet: I-131

Greatest concern

Iodine-131 is easily absorbed through the skin or via inhalation and concentrates in the thyroid gland. Even a small amount of uptake can produce very high radiation dose to the thyroid

Primary hazards to emergency responders

Contamination: -Majority of contamination will likely settle within 100-200 yards of device, but volatile iodine can vaporize and travel far downwind

Radiation: -Radiation levels can be high, but not dangerous, from high-activity sources
-Even heavy contamination will not produce high radiation dose levels

Inhalation: -Gives very high dose to the thyroid if inhaled, iodine is very volatile

Ingestion: -Ingesting I-131 radioactivity will produce a high thyroid dose

Skin contact: -Iodine-131 is easily absorbed through the skin and give a high radiation dose to the thyroid

Possible scenarios

"Dirty bomb" -Conventional explosives used to disperse radioactivity over wide area
-Likely to have high (but not dangerous) levels of contamination near scene
-Greatest dangers likely to be radioactivity inhalation, fires, damaged structures, and utility ruptures
-See tables on the other side of this sheet for boundary recommendations
-PPE should include forced air or filtration to remove iodine, and all skin should be covered with materials that are not permeable to iodine

Irradiation device –This isotope may produce moderate external radiation levels, but it not likely to be used in this manner

Airborne spray -Radioactive materials sprayed into air in public area (stadium, theater)
-May receive harmful radiation dose to thyroid via inhalation
-Best protective actions are to wear breathing protection (particulate) and PPE (gloves, turnout gear or coveralls, shoe covers) prior to entry into area
-May wish to place respirators on victims if airborne rad levels are high

Radioactive fire -Smoke may contain radioactive particles and will spread contamination
-Greatest risk will be from fire
-Water used to extinguish fire likely to contain radioactivity from the fire
-Protective actions should include respiratory protection and PPE
-See the PPE fact sheet

Radiation Fact Sheet: I-131

Radiation Fact Sheet: I-131

Physical and Chemical Data

Radiological properties		Risks		Actions
Radiation type	Beta, gamma	Direct radiation	Moderate	Treat serious injuries
External radiation dose rate	Moderate	Inhalation	Very high	Decontaminate skin
Absorbed through skin?	Yes	Ingestion	Very high	Check for inhaled activity
Penetrating ability	Whole body	Skin contamination	Very high	Check for radiation burns

Boundary line recommendations

The amount of radioactivity may or may not be known. ***If the amount of radioactivity present cannot be determined, assume the incident involves a high level of radioactivity*** and respond accordingly until radiation safety personnel determine otherwise. The radiation levels noted are as would be read on a radiation dose-rate meter, whose operation is described in the Radiation Instruments fact sheet in the first section of this collection.

The greatest risk to victims, responders, and the public is from inhaling, ingesting or direct skin contact.

Dirty Bomb (Radiological Dispersal Device, or RDD)					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Moderate	1500 feet	4500/3000 feet	4500+
Medium	Mod walk	Low-Mod	500 feet	1500/800 feet	1500
Low	Mod walk	Low	150 feet	1200/600 feet	1000

Fire with radioactivity					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Moderate	1500 feet	4500/3000 feet	4500+
Medium	Rapid walk	Low-Mod	500 feet	1500/800 feet	1500
Low	Mod walk	Low	150 feet	1200/600 feet	1000

Airborne spray of radioactivity					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Mod-High	1500	3000/3000 feet	4500+
Medium	Rapid walk	Moderate	750	1500/1000 feet	1500
Low	Rapid walk	Moderate	300	1500/600 feet	1000

Irradiation device (radioactive source in public place)					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Very high	600	5000 feet	4500+
Medium	Mod walk	Mod-high	200	1500 feet	1500
Low	Mod walk	Low-mod	100	600 feet	1000

- A high-activity source has more than 10 Curies of activity, a medium-activity source has 1-10 Curies of activity, and a low-activity source has less than 1 Curies of activity
- A radiation safety professional will help to determine the source activity

For an explanation of the units (Curies, mr, etc.) refer to the Units and Definitions fact sheets.

Radiation Fact Sheet: I-131

Radiation Fact Sheet: Sr-90

Greatest concern

Sr-90 can be found in very high-activity sources that may pose a grave danger. High-activity Sr-90 sources (tens of thousands of Curies) from the former Soviet Union have caused radiation injury. Many of these sources are unaccounted for.

Primary hazards to emergency responders

Contamination: -Most contamination will likely settle within 100-200 yards of device
-Skin contamination can cause local high dose and skin burns

Radiation: -Radiation levels can be dangerously high from very high-activity sources
-Even heavy contamination will not produce dangerous radiation dose levels

Inhalation: -Gives high dose to the bone if inhaled

Ingestion: -Ingesting Sr-90 radioactivity will produce a high dose to the bone

Possible scenarios

"Dirty bomb" -Conventional explosives used to disperse radioactivity over wide area
-Likely to have high (but not dangerous) levels of contamination near scene
-Greatest dangers likely to be radioactivity inhalation, fires, damaged structures, and utility ruptures
-See tables on the other side of this sheet for boundary recommendations
-PPE should include forced air or filtration to remove Sr dust, and all skin should be covered to reduce skin contamination

Irradiation device -Very high-activity sources were used in the former Soviet Union to generate electrical power.
-These sources can generate dangerously high levels of radiation that have caused radiation injury on multiple occasions in recent years
-Sr-90 beta radiation can generate x-rays; Sr-90 decays to Y-90, which emits gamma radiation and is always found with Sr-90

Airborne spray -Radioactive materials sprayed into air in public area (stadium, theater)
-May receive harmful radiation dose to thyroid via inhalation
-Best protective actions are to wear breathing protection (particulate) and PPE (gloves, turnout gear or coveralls, shoe covers) prior to entry into area
-May wish to place respirators on victims if airborne rad levels are high

Radioactive fire -Smoke may contain radioactive particles and will spread contamination
-Greatest risk will be from fire because Sr is not normally in a volatile form
-Water used to extinguish fire likely to contain radioactivity from the fire
-Protective actions should include respiratory protection and PPE
-See the PPE fact sheet

Radiation Fact Sheet: Sr-90

Radiation Fact Sheet: Sr-90

Physical and Chemical Data

Radiological properties		Risks		Actions
Radiation type	Beta, gamma	Direct radiation	Very high	Treat serious injuries
External radiation dose rate	May be very high	Inhalation	High	Decontaminate skin
Absorbed through skin?	No	Ingestion	Moderate	Check for inhaled activity
Penetrating ability	Skin, whole body	Skin contamination	High	Check for radiation burns

Boundary line recommendations

The amount of radioactivity may or may not be known. ***If the amount of radioactivity present cannot be determined, assume the incident involves a high level of radioactivity*** and respond accordingly until radiation safety personnel determine otherwise. The radiation levels noted are as would be read on a radiation dose-rate meter, whose operation is described in the Radiation Instruments fact sheet in the first section of this collection.

The greatest risk to victims, responders, and the public is radiation from very high-activity sources.

Dirty Bomb (Radiological Dispersal Device, or RDD)					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Moderate	1500 feet	4500/3000 feet	4500+
Medium	Mod walk	Low-Mod	500 feet	1500/800 feet	1500
Low	Mod walk	Low	150 feet	1200/600 feet	1000

Fire with radioactivity					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Moderate	1500 feet	4500/3000 feet	4500+
Medium	Rapid walk	Low-Mod	500 feet	1500/800 feet	1500
Low	Mod walk	Low	150 feet	1200/600 feet	1000

Airborne spray of radioactivity					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Mod-High	1500	3000/3000 feet	4500+
Medium	Rapid walk	Moderate	750	1500/1000 feet	1500
Low	Rapid walk	Moderate	300	1500/600 feet	1000

Irradiation device (radioactive source in public place)					
Radioactivity content	**Fall-back speed**	**Radiation risk**	**Initial evacuation**	**Protect downwind (day/night)**	**2 mr/hr boundary (feet)**
High	Rapid walk	Very high	600	5000 feet	4500+
Medium	Mod walk	Mod-high	200	1500 feet	1500
Low	Mod walk	Low-mod	100	600 feet	1000

- A high-activity source has more than 100 Curies of activity, a medium-activity source has 10-100 Curies of activity, and a low-activity source has less than 10 Curies of activity
- A radiation safety professional will help to determine the source activity

For an explanation of the units (Curies, mr, etc.) refer to the Units and Definitions fact sheets.

Radiation Fact Sheet: Sr-90