PNNL-20218

HANDBOOK

for

Response to Suspect Radioactive Materials

January 2011

U.S. DEPARTMENT OF ENERGY

NNSA
National Nuclear Security Administration

This product was developed by the Pacific Northwest National Laboratory for NNSA's Office of the Second Line of Defense

Handbook for Response to Suspect Radioactive Materials

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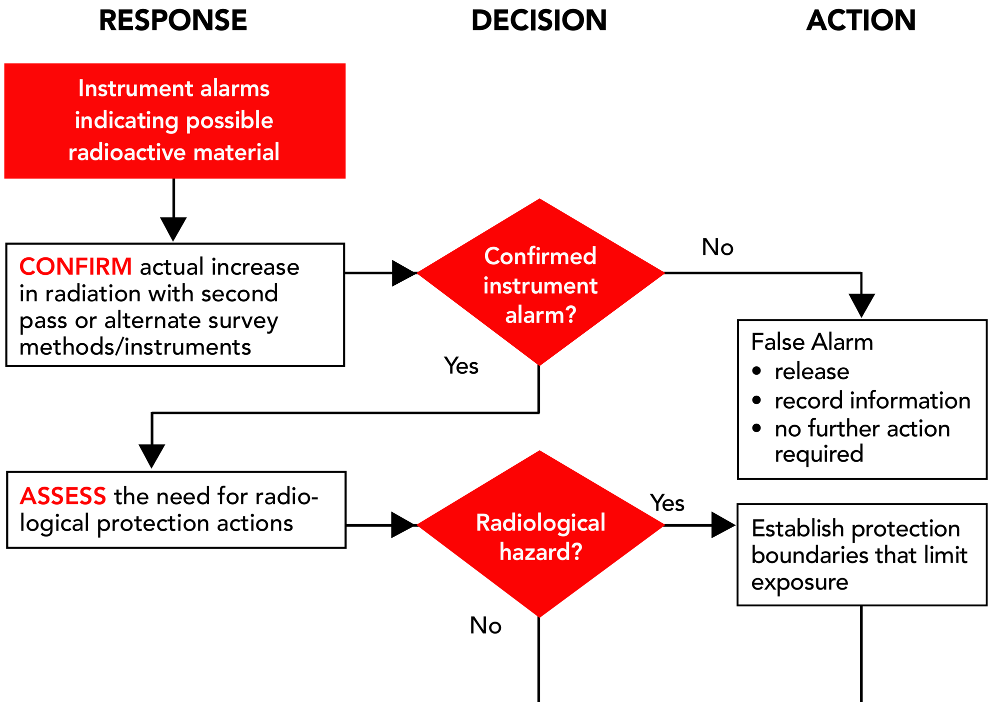
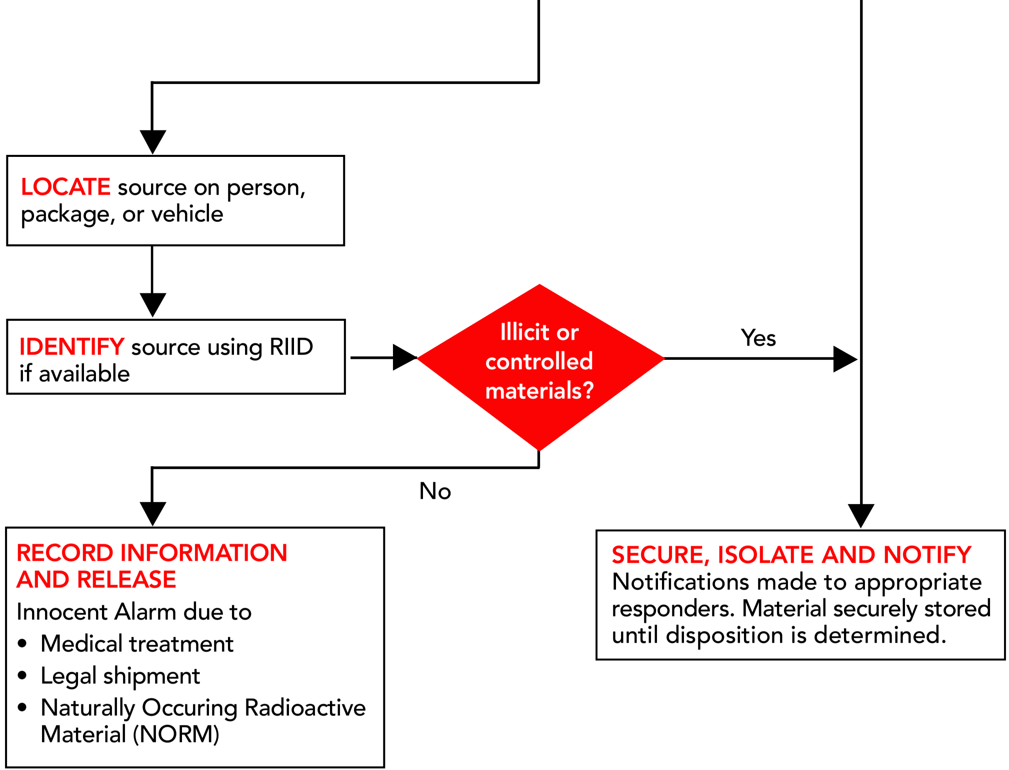
Flowchart Showing the Initial Response to the Identification of Suspect Radioactive Materials.




LOCATE source on person, package, or vehicle
IDENTIFY source using RIID if available
Illicit or controlled materials?
Yes
No
RECORD INFORMATION AND RELEASE
Innocent Alarm due to
• Medical treatment
• Legal shipment
• Naturally Occuring Radioactive Material (NORM)
SECURE, ISOLATE AND NOTIFY
Notifications made to appropriate responders. Material securely stored until disposition is determined.

Response Guide to Portal Monitor Alarms

Portal Monitor Inoperative

Step	Action	Results
1.	Notify competent authority	
2.	Check manifest	
3.	Sweep with hand-held monitors	Negative—release Positive—secondary
4.	If gamma found with hand-held follow the "Portal Monitor Response: Gamma" procedure given below	
5.	If neutron found or suspected with hand-held follow the "Portal Monitor Response: Neutron" procedure given below	

Portal Monitor Response: Gamma

Step	Action	Results
1.	Confirm with hand-held or second pass	Negative—record and release Positive—go to step 2
2.	Isolate vehicle from traffic flow	
3.	Assess hazard from alarm data and manifest information	
4.	Remove driver/passengers from vehicle	
5.	Scan personnel using U-shaped scan—top to bottom, front and back	Negative—hold for final disposition Positive—check for medical isotopes
6.	Scan vehicle, sweeping up and down motion	Consistent low level reading—check manifest for contents (see pg 29) High spike noted—check manifest, continue search

Portal Monitor Response: Gamma (cont'd)

7.	Attempt to identify source using RIID (if available)	
8.	Legal medical isotopes or identified as NORM	Release
9.	Illicit source, illegally transported or unknown radioactivity	Secure, isolate, and notify
10.	Record results	

Portal Monitor Response: Neutron

Step	Action	Results
1.	Confirm alarm with second pass	Negative—Release vehicle and record information Positive—Go to step two
2.	Check manifest for legal shipment	Negative—secure vehicle, isolate, and notify Positive—check for secondary sources, if none, record and release

Acknowledgements

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1.0 Introduction

A goal of the U.S. Department of Energy (DOE) National Nuclear Security Administration (NNSA) is to reduce the risk of illicit trafficking of special nuclear materials (SNM) and other radioactive isotopes that might be used in a weapon of mass destruction (WMD) or radiological dispersal device (RDD) before they reach the borders of the United States. NNSA programs have deployed radiation detection equipment to foreign countries in support of law enforcement since 1997 in response to (1) concerns about the amount of nuclear materials in the Former Soviet Union, (2) the vulnerability of those nuclear materials to diversion, and (3) the demonstrated interest of terrorist organizations and rogue nations in acquiring such materials. NNSA cooperates with the Department of Homeland Security's Customs and Border Protection and complements the Container Security Initiative. NNSA provides radiation detection equipment, training, and support to a prioritized list of the world's largest and busiest ports (Megaports) to enhance the ports' capability to screen container cargo specifically for nuclear and other radioactive materials.

The NNSA radiation equipment deployments require an extensive training program to ensure that border enforcement officials understand how to operate the equipment and respond to alarms, both innocent and those triggered by smuggling attempts. This document is a job aid and reference intended to supplement the NNSA training that promotes operational competency, system responsibility, and long-term program sustainability.

The Nuclear Threat

The WMD nuclear threat can be considered as including two categories of radioactive materials: (1) SNM and other materials capable of producing a nuclear yield, and (2) other radioactive isotopes that might be used in a RDD. The seriousness of the threat is underscored by the number of seizures of weapons-usable nuclear material by law enforcement over the past decade. The International Atomic Energy Agency (IAEA) reports that there have been over 300 interdictions of radioactive material since 1993, 17 of these involving SNM.

SNM is the category of radioactive material used in nuclear weapons that includes plutonium, uranium enriched in Uranium-235, and Uranium-233. Extensive efforts are taken to ensure that the appropriate level of control is maintained during the transport and storage of SNM; however, there have been cases involving the seizure of this type of radioactive material. More than 15 kg of highly enriched uranium and 400 g of plutonium have been seized. The European Police Office estimates that an additional 10 to 30 kg of highly enriched uranium are currently available on the black market.

The RDD differs from a nuclear weapon in that it contains radioactive material, but does not use that material to produce a nuclear explosion. RDDs are constructed of conventional explosives and radioactive material, are designed to disperse radioactive material, and thereby contaminate property and people. The candidate materials for a RDD include radioactive materials used in science, medicine, and industry that have been orphaned or obtained illicitly. RDDs are weapons of mass disruption whose principal impact on a target is the huge economic costs of contamination clean up and social stigma. Many people harbor such an irrational fear of radiation that they would forever avoid visiting a targeted area even though it was completely decontaminated.

Millions of sealed radioactive sources have been distributed worldwide over the past 50 years, with hundreds of thousands to a few million currently being used, stored, and produced. Many of these sources are weakly radioactive and pose little radiological risk. However, the IAEA has tabulated more than 20,000 operators of significant radioactive sources worldwide, including:

- more than 10,000 radiotherapy units for medical care;
- approximately 12,000 industrial sources for radiography that are supplied annually; and
- approximately 300 irradiator facilities containing radioactive sources for industrial applications.

In many countries where the regulatory control of radioactive sources is weak, the inventories are not well known.

With large numbers of sources in use, the possibility of theft and subsequent illicit use of radioactive material exists. The great majority of detected illicit trafficking incidents appear to involve opportunists or unsophisticated criminals, motivated by the hope of profit. In some cases, the theft of sources was incidental to the theft of vehicles; in other cases, the thieves may have been interested in an item's resale value as an expensive instrument or as scrap metal. Nevertheless, it is apparent that an important fraction of cases involved persons who expected to find buyers interested in the radioactive contents of stolen sources and their ability to cause harm or threaten safety.

Customs and other border protection officers, border guards, and police forces have detected numerous attempts to smuggle and illegally sell stolen sources.

Some radioactive sources may be considered "orphaned." Orphaned sources include: sources that were never subject to regulatory control; sources that were subject to regulatory control but subsequently have been abandoned, lost, or misplaced; and sources that were stolen or removed without proper authorization. Exactly how many orphaned sources there are in the world is not known, but the numbers are thought to be in the thousands.

Sealed sources or their containers can be attractive to scavengers for the scrap metal trade because they appear to be made of valuable metals and sometimes may not display a radiation warning label. Cases where unsuspecting people or even members of the public have tampered with sources have led to serious injury and, in some cases, death.

In addition to sealed radioactive sources, there exist large quantities of radioactive waste (derived from the nuclear fuel power industry or weapons production), spent nuclear fuel, and unsealed forms of radioactive material. The potential for radioactive contamination from these types of materials is much greater than from the sealed sources discussed above.

Vigilance at border crossings can significantly reduce the threat posed by illicit movement of radioactive material.

Purpose

This document provides guidelines for appropriate response actions upon the discovery of suspect radioactive materials at a seaport, airport, or land border crossing. With the advent of sensitive radiation detection equipment at borders, standard response procedures must be established that guide the border personnel in the necessary actions to control radioactive materials. Cargo and transport conveyances containing radioactive materials can be identified through:

- radiation detection equipment,
- internationally recognized package labels, and
- shipment manifest declarations.

General information is provided for the use of radiation detection equipment to identify radioactive substances and to ascertain the legitimacy of its transport. There are many innocent and legitimate sources of radiation transported across borders, including naturally occurring radioactive material (NORM) and radioactive medical material. The actuation of a radiation detector's alarm does not automatically imply a hazard or a violation. In fact, experiences at sites employing radiation detection equipment suggest the vast majority of radiation alarms are innocent, due to NORM and radioactive medical materials. Radioactive materials deemed illicit or not in compliance with transport regulations should be processed in accordance with the local, applicable standard operating procedures (SOP).

Implementation Requirements

This document is designed to work in tandem with a training program developed for basic radiation physics and safety, radiation detection systems' operations, and radiation alarm response procedures.

- Fixed and/or portable radiation detection equipment is required to screen cargo, conveyances, and people for radioactive materials.
- All responses to radiation detection incidents should be treated as suspect until proven otherwise.

- It is important that the border site's local response procedure be in accordance with existing procedures for law enforcement and engage experts in the handling of hazardous materials
- It is important that technical expert assistance be engaged in the development and execution of radiation detection response procedures.
- It is essential to establish safety zones in conformance with equipment detection capabilities and applicable health and safety requirements. The guidance provided should be used only after ensuring that applicability to a given monitoring location and circumstance is appropriate.

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2.0 Radiation Basics

Radiation and Radioactivity

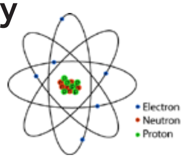

Figure 2-1. An Atom

To develop an understanding of the hazards and necessary precautions associated with radioactive materials, it is important to gain some basic information about radiation. Radiation is the energy emitted (or radiated) from excited atoms. Materials containing excited atoms may occur naturally in our environment or be man made. Natural radiation cannot be completely avoided; however, the levels of natural radiation are low.

All matter is made up of atoms. Atoms are invisible to both the naked and assisted eye. The three basic components of the atom are protons, neutrons, and electrons. The central portion of the atom is the nucleus. The nucleus contains protons and neutrons that are closely bound to each other. Electrons orbit the nucleus.

Only certain combinations of neutrons and protons result in stable atoms.

- If there are too many or too few neutrons for a given number of protons, the resulting nucleus will have too much energy. This atom will not be stable.
- An unstable atom will try to become stable by giving off excess energy in the form of radiation (particles or waves). Unstable atoms are also known as radioactive atoms.

When most people think of radiation, they think of the type that comes from atoms. There are, however, many different kinds of radiation. Visible light, heat, radiowaves, and microwaves are all types of radiation but they are not the types we are concerned about in this document. In this document, when we speak of radiation, we are talking about ionizing radiation, which is radiation with sufficient energy to remove an electron from an atom.

Radioactive Material and Radioactivity

Radioactive material is any material that emits radiation. The process of an unstable atom emitting radiation is called radioactivity.

Radioactive atoms can be produced through nuclear processes, but they also exist naturally; the most common NORM are uranium, thorium, and potassium. When a radioactive atom goes through the process of radioactive disintegration, also called radioactive decay, it generally changes to another element. For example, the element uranium will eventually change through radioactive decay to lead, as illustrated in Figure 2-2.

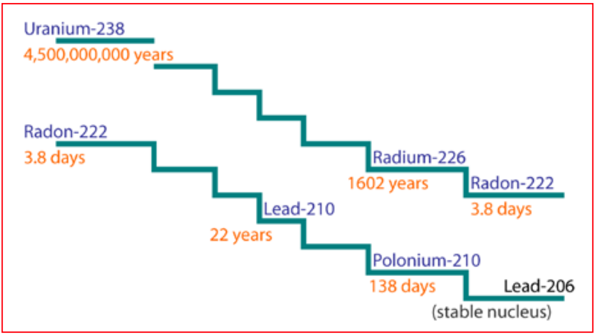

Figure 2-2. The Decay Chain for Uranium-238

Parts of this stabilizing process may take from a fraction of a second to billions of years, depending on the particular type of atom.

Radioactive Material Half-Life

The rate of radioactive disintegration is a measure of the activity. The specific activity is the number of disintegrations per gram of material. A common regulatory limit to define radioactive materials is 74 Bq/g or 2 nCi/g.

The rate of radioactive decay is unique to each type of radioactive atom and is often expressed as the half-life, the time it takes for half of the radioactive atoms in a sample to decay to another form. For example, some radioactive pharmaceutical products (called radiopharmaceuticals) have half-lives that range from a few hours to a few months. It is important to note that radioactivity is constantly decreasing. After seven half-lives, the material will be at less than 1% of its original activity.

The following are some common materials and their respective half-lives:

Isotope	Common Use	Half-Life
Americium-241	Smoke detector	432 years
Technicium-99m	Nuclear medicine	6 hours
Iodine-131	Nuclear medicine	8 days
Plutonium-239	Nuclear energy	24,000 years

Radioactive Contamination

Radioactive contamination is undesired radioactive material deposited on the surfaces of, or inside of structures, areas, objects, or people. Simply speaking, radioactive contamination is radioactive material in an unwanted location.

When radioactive material is properly used and controlled, there are many beneficial applications. Most smoke detectors, for instance, use radioactive material, as do certain medical diagnostic tools and treatment procedures. It is only when radioactive material is where it is not wanted (e.g., on the ground, in water, or on you) that we refer to it as contamination.

Radiation vs. Contamination

One of the most important concepts for border control personnel to understand is the difference between radiation and contamination. Radiation is energy emitted by radioactive material.

Figure 2-3. Contamination vs. Radiation

Contamination is radioactive material in a location where it is not wanted. It is important to understand that a person exposed to radiation does not become radioactive or contaminated. On the other hand, radioactive contamination emits radiation. If a person is contaminated with radioactive material, the person continues to be exposed to radiation until the contamination is removed.

If packages or containers of radioactive materials (i.e., radioactive waste or unsealed forms of radioactive material) are damaged or broken, then smearable (loose or removable) contamination may be present. Smearable contamination may be on the outside of packages as a result of leakage from radioactive sources. Smearable contamination can easily contaminate personnel and be spread to large areas by handling and moving contaminated materials. Border personnel who encounter possible contamination should secure the area and notify the proper authority as prescribed in their SOP.

Exposure to Radioactive Material

If you encounter radioactive material at an incident scene, you may be exposed to radiation. Even with the tightest package and the best protection required for a legal shipment, low levels of x- and gamma-radiation can pass through the package.

This radiation is at a level that is (based on numerous scientific studies by a variety of industry, scientific, and government organizations) considered safe for people working near the packages. If the packages are intact, you should not expect unsafe exposure. This is of course assuming that the material is packaged properly and is not intended for illicit purposes. You should remember that we are exposed to radiation every day from common sources such as cosmic rays, x-rays, and even the bricks used to make buildings. Appendix C has additional information on natural background radiation.

Routes of Entry for Radioactive Material to Enter the Body

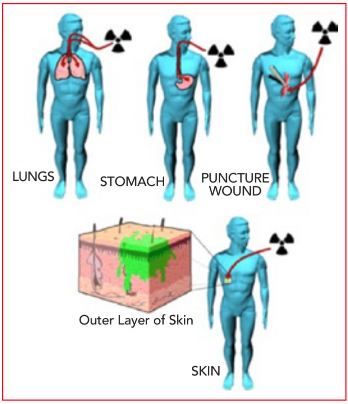

Figure 2-4. How Radioactive Contamination Enters the Body

Internal radioactive contamination results when radioactive material gets into the body. Your skin, mouth, and nose are the most obvious—and avoidable—routes to internal contamination.

Radioactive material can enter the body through the same pathways as any other material.

Biological pathways that can introduce internal contamination include:

- *Inhalation*—smoke particles or other airborne particulate matter may enter the body into the lungs as you breathe.
- *Ingestion*—eating, drinking, smoking, or chewing contaminated items may cause internal radiological contamination.
- *Absorption*—radioactive material may occasionally be absorbed through the skin or mucous membranes.
- *Injection*—radioactive material can be introduced to the body through cuts, wounds, direct medical injections, or other punctures in the skin.

Radiation Risk

Through scientific research, ionizing radiation dose has been identified as a potential cause of cancer in humans. Based primarily on studies made of the survivors of the atomic bomb blasts in Hiroshima and Nagasaki, estimates indicate that of the 91,000 survivors, 6,270 have died from cancer. The typical number of cancer-related deaths for this population would be 6,039. In other words, the radiation received by the atomic bomb survivors may have contributed to an additional 231 cancer related deaths. The National Academy of Sciences, National Council on Radiation Protection and

Measurement, and the International Commission on Radiation Protection estimate the average risk to an adult of fatal cancer from radiation in his/her lifetime is four in 10,000 per 10 mSv (1 rem) of radiation dose. In other words, an additional four deaths may occur due to radiation-induced cancers in a group of 10,000 people, if each of them receive an additional exposure of 10 mSv (1 rem).

Radiation can also come from radiation generating devices. In some cases, such as an x-ray unit used for medical purposes or for screening luggage, the device does not contain radioactive material. Radiation produced by these machines penetrates materials but this radiation does not make them radioactive. Other radiation generating devices such as pipe radiographic sources, well-logging equipment, or industrial irradiators for food irradiation or medical supply irradiation will contain radioactive sources, which if unshielded, can pose a significant health threat.

Radiation emitted by radioactive materials can be one or more of several types with unique characteristics. The types of radiation are shown in Figure 2-5 along with the types of material that can effectively shield the radiation.

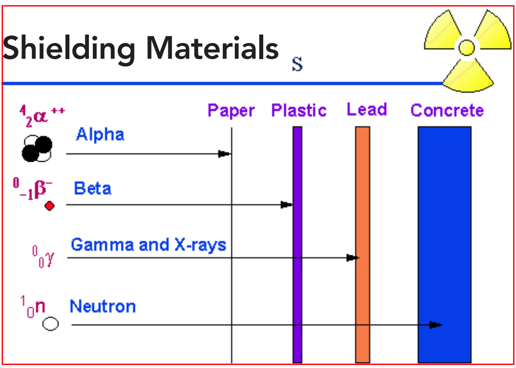

Figure 2-5. Types of Radiation and Shielding

Note that radiation with a charge, such as alpha and beta particles, is easily stopped by thin materials, including skin. Hence, alpha- and beta-particle emitters do not pose a health risk if kept outside the body, and only become harmful if inhaled or ingested. Also, alpha- and beta-particle detectors are not useful for detecting radioactive material crossing borders since only neutron and x-rays or gamma rays are penetrating enough to be detected outside the packaging. However, sometimes beta-particle emitters are detected because of bremsstrahlung, a type of x-ray produced as the beta particles are slowed and stopped inside the material and shielding.

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3.0 Radioactive Material Transportation

Radioactive material has many uses that affect us every day. Radioisotopes save lives by helping doctors diagnose and treat illnesses. They also make our lives safer. One kind of radioisotope is used in a smoke detector and another in an explosive detector for screening airport luggage. Radioisotopes are also used in devices for measuring thickness during manufacture of everyday products like plastic wrap, radial tires, and coffee filters. For a radioactive material to be useful, it must be shipped where it is needed. Shipments of radioactive material are carefully regulated to maximize safety to the public and environment.

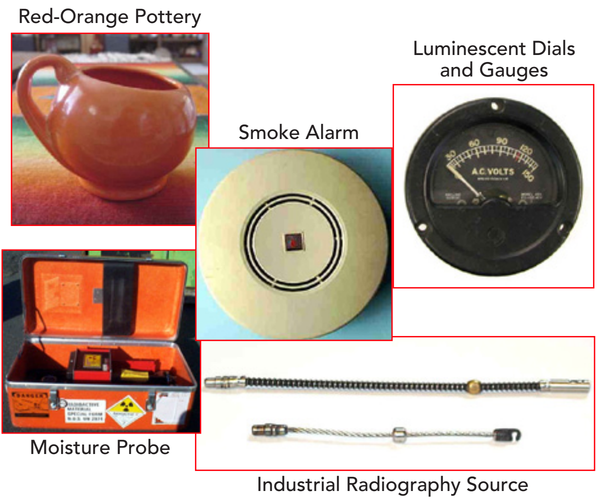

Figure 3-1. Examples of Common Items Containing Radioactive Material

Radioisotopes are shipped in their most stable forms, typically as solids. When radioactive liquids or gases are transported, regulations usually require additional precautions. Careful research and design goes into packaging radioactive materials.

Figure 3-2. Examples of Packaged Radioactive Materials

International regulations place strict administrative controls on the transport of radioactive material. The worldwide philosophy of radioactive material transport is that:

- Safety should be primarily focused on the package. Packaging is the first line of defense.
- Package integrity should be directly related to the degree of hazard of the material it contains.

This two-part philosophy means that small quantities of radioactive material—quantities that would present little hazard if released—may be shipped in less secure packages.

Radioactive material, like other commodities, is transported every day by highway, rail, air, and water. Radioactive material is packaged to ensure that radiation levels at the package surface do not exceed regulations governing allowable dose and radiation exposure to shippers and the public. The packaging is also in compliance with regulations designed to minimize the risk of contamination. This ensures that shippers, the public, and the environment are not exposed to radiation levels that exceed recognized safe limits. After radioactive material is properly packaged, it is sealed, surveyed for external radiation levels, and checked for external contamination. The package is then marked and labeled to provide information about its contents.

Different packaging is required for various types, forms, quantities, and levels of radioactivity. Four packaging types are:

- Excepted Packaging
- Industrial Packaging
- Type A Packaging
- Type B Packaging

Excepted Packaging is used to transport material with extremely low levels of radioactivity. Excepted packaging is authorized for limited quantities of radioactive material that would pose a very low hazard if released in an accident. Examples of goods packaged in excepted packaging are consumer goods like smoke detectors, lantern mantles, and thoriated welding rods.

Figure 3-3. Excepted Package

Industrial Packaging is used in certain shipments of low activity material and contaminated objects that are usually categorized as radioactive waste. Most low-level waste is shipped in such packages.

Figure 3-4. Industrial Package

Type A Packaging is used to transport small quantities of radioactive material with higher concentrations of radioactivity than those shipped in industrial packagings. They are typically constructed of steel, wood, or fiberboard, and have an inner containment vessel made of glass, plastic, or metal surrounded with packing material made of polyethylene, rubber, or vermiculite. Type A packagings are used to ship nuclear medicines (radiopharmaceuticals), radioactive waste, and radioactive sources used in industrial applications.

Figure 3-5. Package Type A

Figure 3-6. Package Type B

Type B Packaging is designed to transport material with the highest level of radioactivity. Type B packaging ranges from small hand-held radiography cameras to heavily shielded steel casks that weigh up to 125 tons. Examples of material transported in Type B packaging include spent nuclear fuel, high-level radioactive waste, and high concentrations of other radioactive materials such as Cesium-137 and Cobalt-60.

Air Transportation

Transportation of radioactive material by air is very tightly regulated. The pilot of the aircraft must sign a manifest acknowledging the presence of the material on the plane. Radioactive material on aircraft must be in packaging that is able to withstand the conditions of air transport, such as pressure changes, and must be stored in designated locations. Most radioactive medical material is shipped by air.

Rail Transportation

Rail transportation may be used for all types of radioactive material shipments. The most significant difference between rail and truck is the size of the package. Trains can carry the largest and heaviest of the Type B packages, which are too large for trucks. In addition, trains are often used to carry large volumes of low-level radioactive waste.

Truck Transportation

Most shipments of radioactive material are made by truck. Packages used in truck transport include all of those described previously. Some high activity level shipments must be shipped over specific routes to provide maximum safety and security.

Water Transportation

Transport of radioactive material by water exists in two broad classifications: ocean and river. Ocean transport of radioactive material includes both low-level radioactive ores and high-level items such as used reactor cores. Vessels carrying radioactive material into the United States must obey very stringent Coast Guard regulations regarding entry into U.S. waters. River vessels carry material similar to that shipped by truck or train. Access to suitable port facilities, and the resulting need to transfer the material from barge to truck or train, limits the transport of radioactive material by water.

Radioactive Shipment Limitations

Generally, a company cannot offer a number of individual packages of radioactive material that will cumulatively exceed a total of 50 TI (Transport Index). This means that if a company has 20 packages, each with a one meter reading of 3.0 TI, it cannot offer to the carrier more than 50/3, or 16 packages.

The international packaging labels and their associated dose rate and TI limits are shown in Figure 3-7.

	Category- I White Label	Category-II Yellow Label	Category-III Yellow Label
Surface Dose Rate	< 0,005 mSv/h	0,005 mSv/h to 0,5 mSv/h	0,5 mSv/h to 2 mSv/h
Transport Index	0	0 to 1	1 to 10

Fissile materials labels are required for packages containing U-233, U-235, Pu-239 or Pu-241

Figure 3-7. Radioactive Material Labeling

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4.0 Monitoring

Figure 4-1. Radiation Cannot be Detected by Our Senses

Radiation cannot be detected by any of our senses. By using radiological survey instruments, properly trained operators can easily and accurately detect radiation. Two general categories of radiological survey instruments are available. One category of instruments is designed to measure dose rate, while the other is designed to provide count rate for the detection of sources and the measurement of contamination. Some instruments are designed to measure both dose and count rate. Radiation measuring instruments provide dose rate measurements (μSv/hr or mrem/hr or μR/hr) and detection/contamination measuring instruments provide a count rate (detections or counts per minute or counts per second.

Monitoring instruments will not distinguish between fixed and smearable contamination. Survey for smearable contamination is performed by qualified personnel by wiping the outside of packages containing radioactive materials with a clean cloth, moving to an area away from the radioactive material, and surveying the cloth using monitoring instruments. Packages with smearable contamination should not be handled without appropriate precautions. Border personnel who encounter possible contamination should secure the area and notify the proper authority as prescribed in their SOP.

The detection capability of radiation monitoring equipment depends on the amount and type of radiation emitted by the source and also on the presence of any shielding materials that may reduce the amount of radiation that reaches the detector. The radiation detection equipment deployed by NNSA is designed to detect both SNM and other radioactive materials that could be used in a RDD. SNM typically emits low-energy gamma radiation. Plutonium is unique in that it is also a neutron emitter.

The purpose of a radiation exposure survey is to locate and measure sources of radiation. Radiation exposure surveys are useful for the following:

- Establishing control zone boundaries
- Controlling personnel exposure
- Assessing package integrity
- Locating sources of radiation.

Radiation surveys should be initiated with low-range survey instruments, which are better at detecting lower levels of radiation. Prior to use, verify the radiation detection equipment is functioning properly as specified in applicable SOPs. Follow your local procedures or manufacturer's recommendations on instrument pre-operational checks and instrument calibration frequency. Prior to performing a radiation survey, verify that the instrument is on and a visual response registers on the meter.

Monitoring for radioactive materials at ports and border crossings can be accomplished with a number of different types of equipment. These most commonly are grouped into the following four categories:

- **Personal Radiation Detector (PRD).** A radiation detector approximately the size of a pager that can be worn by border control officers. The device can provide a flashing light, tone, vibration, or a numerical display that corresponds to the level of radiation present. Electronic dosimeters are also available from various manufacturers in a variety of sizes and shapes. There are many options available, depending on the required or desired response. Check manufacturer specifications for dose rate response characteristics.

Figure 4-2. Personal Radiation Detector

- **Handheld Survey Instruments.** A radiation detector used to identify the location of radioactive materials that provides greater sensitivity than pocket-type instruments. The instrument can provide an alarm and numerical display that corresponds to the level of radiation present. A limitation of radiation exposure survey instruments is that they are generally not as sensitive as contamination survey instruments and may not efficiently detect some types of contamination.

Figure 4-3. Handheld Survey Instrument

- **Radiation Portal Monitor**. A pass-through monitor typically consisting of two pillars containing radiation detectors and monitored from a display panel. The instrument can provide alarming capability to indicate the presence of radioactive material above a preset limit.

Figure 4-4. Vehicle Portal Monitor

- **Radioactive Isotope Identification Device (RIID)**. A radiation detector that analyzes the energy spectrum emitted by radioisotopes for identification. They can also be used as survey instruments to locate radioactive material.

Figure 4-5. Radioactive Isotope Identification Device

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5.0 Response Goals

The goal of any response to the detection of suspect radioactive materials in a border control environment is to minimize the potential health hazards to the public and border control officers and bring the radioactive materials under the appropriate control. Response procedures must account for the immediate protection of border control officers, response personnel, and the general public.

The initial detection of radioactive material in cargo, conveyances, or people will likely be due to a portal monitor alarm. Effective response procedures are critical for determining if the radioactive material is innocent, illicit, and/or hazardous. To accomplish the safe, efficient, and thorough secondary evaluation of any radiation alarm requires a five-step process involving:

(1) **confirmation** that radioactive material is present,

(2) **assessment** of the hazard the radioactive material presents,

(3) determination of the exact **location** of radioactive material,

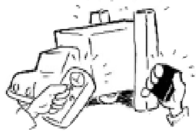
(4) **identification/control** of the radioactive material, and

(5) **secure** and **isolate** the material and **notify** the proper authorities.

Additional actions such as exposure assessment, casualty response, criminal investigation, and media contacts may be necessary depending on the significance of the material discovered.

Normally the verification of an alarm, searching for the radioactive material, and performing a cursory radiological assessment are one continuous process even though they are discussed separately.

Confirm



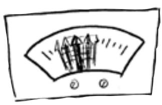
Safety should always be the first operational thought when processing any radiation alarm. The tool of choice for ensuring the personal safely of border control officers is the PRD. When approaching a vehicle, container, or person in response to an alarm, the officers should check his/her PRD to verify that it indicates a safe level of radiation. Most PRD devices provide readings that can be compared to safe radiation levels as dictated in international regulations for the transport of radioactive materials. Keep in mind that a person handling radioactive material for illicit purposes is taking an enormous risk and may pose a danger to you or others in the vicinity.

Each radiation alarm needs to be verified to exclude false alarms. Verification involves repeating the measurement process to confirm the initial indication of a radiation field. For fixed radiation portal monitors, it may mean that the vehicle needs to be passed through the monitor a second time to obtain a repeat measurement. Alternately, the vehicle can be isolated from the traffic flow and subjected to an inspection using a handheld radiation detector.

During confirmation, the user needs to keep in mind that the sensitivity of the monitoring device can be improved if it is used closer to the radioactive material. Also, an instrument is more likely to detect radiation when it is moved slowly over the area to be scanned.

When surveying for radiation, measurements should be made by approaching the area or object to be surveyed with the detector extended in front of you. Periodically monitor in a 360° circle to ensure that you have not walked by a source of radiation. Monitor for radiation with the detector at waist level and periodically check above and below this level. When a source of radiation is discovered, survey as necessary to determine its approximate location. When performing a radiation survey, it is useful to listen to the audio response, if the instrument has this capability, so that even if you are temporarily distracted, the response to a radiation field can be heard.

Assess Hazards



Radiation Safety

If there is a confirmation that radioactive material is present, the next step is to query any associated individual (medical treatments, professions, shipment content, etc.) to help identify the possible cause of the alarm; however, always be cognizant of safety.

If the border control officer encounters any of the following conditions, the radiation alarm incident is likely to require prompt radiological evaluation due to the potential hazards:

- radiation levels in excess of 0.1 mSv/hr or (10 mrem/hr) at 1 meter from the surface or object
- confirmed detection of neutron radiation (neutrons may indicate the presence of plutonium or a commercial neutron source (see Appendix D)
- radioactive contamination indicated by spilled or leaking radioactive material.

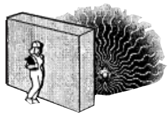
If such a situation should occur, the primary objectives must be:

- personal safety and the safety of individuals in the vicinity
- securing the site so that nonauthorized personnel are protected and excluded from the site
- isolation of the radioactive source (as a general guide, consider a safe distance from the source to be that where the dose rate has dropped to below 0.02 mSv/hr (2 mrem/hr)
- notification to site supervision or other proper authorities.

The border control officer should be familiar with the following three methods for reducing the potential radiation dose:

- **Minimize the time of exposure**. Reducing the amount of time in a radiation field lowers the dose received. Do not loiter around a suspected radiation source and work efficiently while in the vicinity of a source.

- **Increase the distance from the source**. Use the protection offered by distance from the source of radiation whenever possible. Radiation levels will decrease dramatically the further one is removed from the source. If the distance from the source is doubled, the radiation level decreases by a factor of four. Consider using long handled tools, segregating suspected radiation sources away from other work areas or items, and using mirrors or closed circuit television to monitor the area.



- **Use shielding to lower the dose rate**. Shielding can be an effective method for exposure reduction. This can include equipment or existing structures and wearing eye protection if beta radiation is suspected. The following table provides thicknesses to reduce gamma radiation dose rates by one-half:

Table 1. Shielding Properties of Common Materials to Minimize Exposure to Gamma Radiation

Material	Half-value layer thickness*
Steel	2 cm
Concrete	6 cm
Earth	8 cm
Water	12 cm
Wood	22 cm

*Thickness required to reduce the incident dose or dose rate by one half Reference: USACHPPM Tech Guide 244, The Medical NBC Battlebook, August 2002.

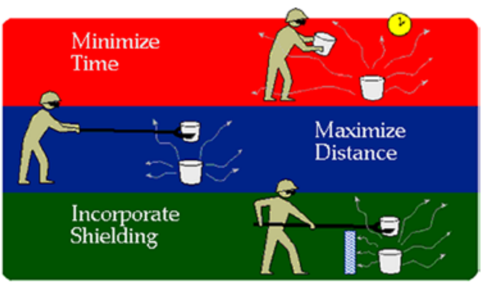


Figure 5-1. Radiation Protection Actions

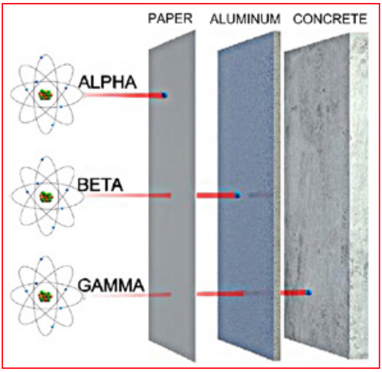
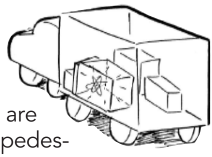


Figure 5-2. *Radiation Shielding*

Additional incident support may be needed for on-scene control, radiological assessment, and incident investigation.

Locate Source



The effectiveness of the search is highly dependent on the techniques and instruments used. Different techniques are discussed below for searches involving pedestrians, packages, vehicles, and cargo. It is important to separate the person from the vehicle or packages.

To conduct a thorough, effective search, the monitor must be scanned over the surface of the object of interest. It is important that during scanning the instrument is maintained at a close distance to the surface (approximately 5 to 10 cm [2 to 4 inches]) without making contact. In addition, instruments are typically more sensitive if they are moved slowly over an area. A reasonable guide would be to move the detector or its probe at about 20 cm/s (~8 inches per second).

The nearer a monitor is to a radioactive source, the greater the radiation intensity and the easier it is to find the material. If an elevated reading is discovered, the user should pause at that location and continue surveying slowly in the direction of increasing source strength until a maximum level is reached. Consideration should be given to how rapidly the source strength is changing. If the dose rate changes rapidly as the instrument is moved, this would indicate a small confined source. On the other hand, a small change over a large area in an elevated reading would indicate a larger volume of material such as a naturally radioactive bulk shipment.

Pedestrians

- Separate packages from the pedestrians carrying them to allow an independent search of each item/person.
- Pace your scan, allow approximately 20 to 30 seconds per individual.
- Ensure a complete check. Start with one foot and scan up one side of the body to the head, then down the other side to the other foot. Then scan the front and back of the body in a similar fashion.

Packages

- Pass the monitor over the object (briefcases, purses, packages, and luggage) just as you would a person.
- Consider having the passenger open but do not permit access to bulky, heavy items if shielding may be present.
- If a package cannot be opened, perform a slower external scan of all sides.

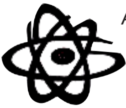
Conveyances – Air, Rail, Train, Vehicle

- Search the occupants of the conveyance as well as the vehicle.
- Visually scan for large, heavy objects that could be in use as shielding.
- Scan accessible surfaces, both interior and exterior, of the vehicle staying close (5 to 10 cm).
- Check bumpers and wheel wells.
- Check truck beds even if empty to look for material attached to the underside and built-in traps.

Figure 5-3. Vehicle Survey Using a Handheld Instrument

- For large vehicles, use a step ladder or an extension for the instrument to reach higher locations.

Identify Source



A further step in the evaluation of the nature of an alarm involves the identification of the specific radionuclides that are found. Identification of the radionuclide will help in the assessment as to whether or not the alarm is due to an innocent or illicit shipment. Activities appropriate in the identification can include application of radiation detection equipment capable of radionuclide identification, interviews with the personnel involved, shipping documentation review, cargo inspection, and support from outside experts in radionuclide identification.

It is important to be alert to the possibility of illicit material being transported along with or in a legal shipment of radioactive material. If a commodity causes an alarm and is found to contain NORM, such as Potassium-40, Thorium-232, etc. (see Appendix D), the cargo should be inspected to verify that any radiation is emitted uniformly around the bulk material.

If the determined safe distance (whenever the dose rate is below 0.02 mSv/hr or 2 mrem/hr) is 3 meters (10 feet) or less from the source, an approximate 3-minute physical examination may be conducted.

If the determined safe distance is beyond 3 meters from the source, call for technical assistance (through agency pre-established channels) if no other options exist for on-scene assessment.

Red Flags – Indications of Potential Illegal Exports

The following are possible indicators of illegal exports or diversions:

- The customer is willing to pay cash for a high-value order rather than use a standard method of payment that usually involves a letter of credit.
- The customer is willing to pay well in excess of market value for the commodities.

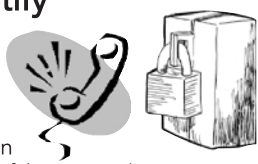
- The purchaser is reluctant to provide information on the end-use or end-user of the product.
- The end-use information provided is incompatible with the customary purpose for which the product is designed.
- The final consignee is a trading company, freight forwarder, export company, or other entity with no apparent connection to the purchaser.
- The customer appears unfamiliar with the product, its application, support equipment, or performance.
- The packaging requirements are inconsistent with the shipping mode or destination.
- The customer orders products or options that do not correspond with their line of business.
- The customer has little or no business background.
- The order is placed by firms or individuals from foreign countries other than the country of the stated end-user.
- The order is being shipped via circuitous or economically illogical routing.
- The customer declines the normal service, training, or installation contracts.
- The product is inappropriately or unprofessionally packaged (e.g., odd sized/retaped boxes, hand lettering in lieu of printing, altered labels, or labels that cover old ones).
- The size or weight of the package does not fit the product described.
- "Fragile" or other special markings on the package are inconsistent with the commodity described.

In the event illicit radioactive material is discovered, notifications should be made in accordance with the site-approved response procedure. Material identified should be isolated and stored in a secure location until the disposition can be determined.

- If the source identified is consistent with the list of innocent radiation sources or NORM (Appendix D), no other isotopes are identified and no inherent danger is discovered, document the incident and release the person, vehicle, or conveyance.

- If the source is an occupant or pedestrian, isolate the traveler and question them with regards to previous medical treatments, areas visited, and profession. If the individual's answers are consistent with medical treatments, the radiation is from the appropriate portion of the body, and the identified radionuclide is consistent with medical procedures (Appendix D), document the incident and release the individual.
- If the source is on the conveyance, conduct a complete radiation survey of the conveyance to locate and identify the type of radiation. If the radioactivity location correlates with the materials described in the manifest for the conveyance and is found on the list of innocent radiation sources or NORM (Appendix D), document the incident and release the vehicle or conveyance.
- If the source identified is not found on the list of innocent radiation sources or NORM (Appendix D), or the level and distribution of the radioactivity does not correlate with the materials described in the manifest for the conveyance, then document the incident and request technical assistance (through agency pre-established channels) for further guidance.

Secure, Isolate, and Notify



When securing the material, ensure that it is isolated in a location not accessible to the general public or others, as deemed appropriate, preferably in a locked location depending on the sensitive nature of the material. For personnel safety, the material should be safely stored to minimize any further radiation exposure. Techniques, as discussed previously, include minimizing **time** personnel need to spend around the material, maximizing the **distance** between personnel and the material, and providing **shielding** to minimize the dose rate from the material.

Notifications are made in accordance with the approved SOP and may include customs and border protection supervision, law enforcement, hazardous material experts, or scientific support agencies. Border control personnel should employ a standard information form or document to convey important incident details during notifications.

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6.0 Decontamination

In the event contamination is suspected or confirmed on either individuals or objects, the decontamination effort should be conducted as soon as possible. In most cases border control personnel will secure the area and notify the appropriate responders in accordance with their approved SOP. The methods for decontamination will depend on the contaminant involved, amount of skin area affected, skin condition, and the severity of the contamination. Every effort must be taken to prevent the contamination from getting into the body. As discussed earlier, this could occur through entry into wounds or eyes, through breathing into the lungs, or through entry into the mouth followed by swallowing. Some materials, such as tritium, can pass directly into the body through skin absorption. Do not decontaminate to the point of causing damage to the skin.

Removal of contaminated clothing and equipment can provide significant hazard reduction to the individuals involved as well as the response personnel. Once removed, contaminated clothing needs to be placed in bags, tagged, and removed to a remote location to avoid creating a hazard and potential for cross contamination. Another technique that can significantly help control the spread of contamination is the use of gloves, ideally changed periodically.

Surface contamination monitoring equipment can be used to assess the degree of decontamination success. The most effective agents for the initial decontamination attempt are soap and water. Special attention should be paid to the hair, hands, and fingernails. Other, more harsh cleaning agents should only be used by medical personnel. Washcloths or towels should only be used once to avoid cross contamination. If several decontamination attempts are not successful, it is recommended that the individual receive medical attention for further attempts. All towels or other materials that come in contact with the affected person should be disposed of as radioactive waste. For transport, personnel should be wrapped in clean cloth to prevent spreading the contamination to vehicles and medical treatment facilities.

Similar efforts can be taken to decontaminate personal effects (shoes, clothing, etc.) or equipment. However, if the contamination is deemed significant, disposal of the items may be the most appropriate option.

7.0 References

National Council on Radiation Protection and Measurements, Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources, Report No. 95, Bethesda, Maryland, 1987.

USACHPPM Tech Guide 244, The Medical NBC Battlebook, August 2002.

Radiological Dispersal Device Detection and Transportation Sub-Group, Check Point Portal Radiation Detector Generic Standard Operating Procedure, November 2002.

United States Department of Energy, Transportation Emergency Preparedness Program, Modular Emergency Response Radiological Transportation Training.

Some photos are from a web-based collection derived from the Health Physics Historical Instrumentation Museum Collection that is the property of the not-for-profit Oak Ridge Associated Universities Foundation and is located at the Professional Training Programs training facility in Oak Ridge, Tennessee.

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8.0 Appendices

Appendix A: Flowchart Showing the Initial Response to the Identification of Suspect Radioactive Materials

Appendix B: Glossary

Appendix C: Radiological Health Information

Appendix D: Major Isotopes of Concern and Common Innocent Radiation Sources

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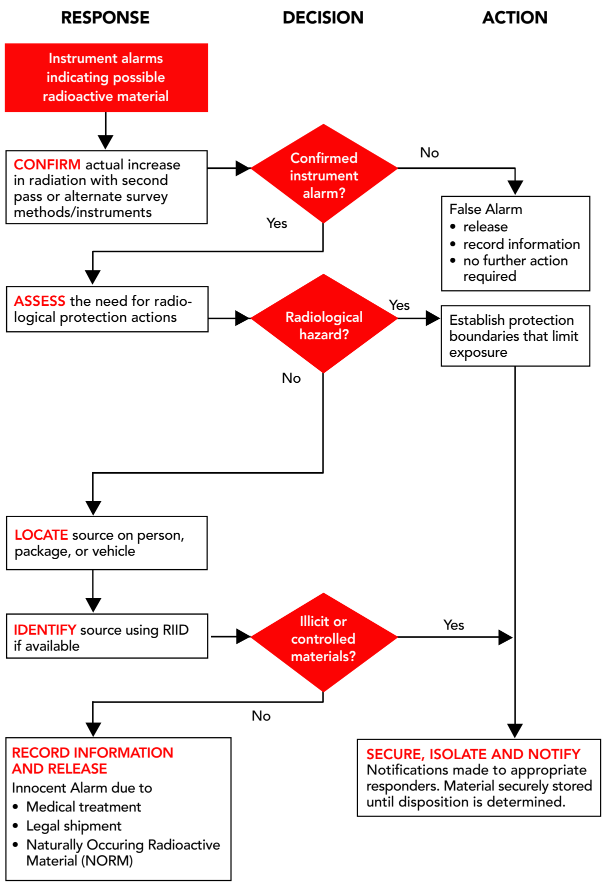
Appendix A:

Flowchart Showing the Initial Response to the Identification of Suspect Radioactive Materials



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Appendix B: Glossary

alpha particle	A positively charged particle ejected spontaneously from the nuclei of some radioactive elements. It has low penetrating power and a short range—a few centimeters in air. Even the most energetic alpha particles fail to penetrate the dead layers of cells covering the skin and are easily stopped by a sheet of paper. Alpha particles only represent a health risk when in direct contact with unprotected tissue, such as lung tissue, or when alpha-emitting materials are deposited inside the body.
background radiation	Radiation from naturally occurring sources and a few man-made sources. NORM includes thorium, uranium, potassium, and radon. Additional exposure to radiation include man-made sources such as x-rays and other medical procedures and radiation emitted by certain consumer products and global fallout. The typical average individual exposure from background sources of radiation is 3.6 millisieverts (360 millirem per year) or 10 microsieverts per day (1 millirem per day) of which roughly 2 millisieverts (200 millirem) come from radon products inside the body.
becquerel (Bq)	The unit of radioactive decay equal to 1 disintegration per second. The becquerel is the basic unit of radioactivity used in the international system of radiation units, also referred to as "SI" units. 37 billion or 3.7×10^{10} becquerel (Bq) = 1 curie (1Ci)
beta particle	A charged particle (equivalent to an electron or positron depending on charge) emitted from a nucleus during radioactive decay. Exposure to large amounts of beta radiation from external sources may cause skin burns (erythema). Beta emitters can also be harmful if they enter the body. Beta particles are stopped by thin sheets of metal or plastic.

contamination	Radioactive material in an unwanted location such as inside or on the surfaces of structures, areas, objects or people. Contamination may be either fixed (tightly bound to a surface), smearable (loosely adhering and easily removed by wiping), or air-borne (inhalable).
control zone	A perimeter established around a source of radiation or contamination to minimize exposure to workers and the general public. See also safety zone.
curie (Ci)	A unit of radioactivity used in the system of traditional units. The curie is equal to $2.2x10^{12}$ disintegrations per minute or $3.7x10^{10}$ disintegrations per second. 1 curie (Ci) = $3.7x10^{10}$ becquerel = 37 GBq
daughter products	Same as decay products.
decay products	Nuclides formed by the radioactive decay of parent radionuclides. For example, radium, specifically Radium-226, eventually forms nine successive radioactive decay products in what is called a "decay chain." Each decay product has a unique radioactive half-life and mode of disintegration. Some, such as radon with a 3.8-day half-life or Polonium-214 with a 0.16 millisecond half-life, are short-lived, while others, such as Lead-210 with a 22.3-year half-life, are relatively long-lived. The radium decay chain ultimately ends with the formation of Lead-206, which is one of several stable isotopes of lead.
decontamination	The reduction or removal of contaminating radioactive material from a structure, area, object, or person.
depleted uranium	Uranium having a percentage of Uranium-235 less than the 0.72 percent found in natural uranium. It has roughly the same density as natural uranium, gold, tungsten, or plutonium. Although slightly radioactive it is occasionally used as shielding in packages used to transport radioactive material.

dose	A general term used to refer to the effect on a material that is exposed to radiation. It is used to refer either to the amount of energy absorbed by a material exposed to radiation (see also dose, absorbed) or to the potential biological effect in tissue exposed to radiation (see also dose, equivalent).
dose, absorbed	The amount of energy deposited in any substance by ionizing radiation per unit mass of the substance. It is expressed numerically in rads (traditional units) or grays (SI units).
dose, equivalent	The product of absorbed dose in tissue, multiplied by a quality factor and then sometimes multiplied by other necessary modifying factors to account for the potential for a biological effect resulting from the absorbed dose. (See also quality factor). It is expressed numerically in rems (traditional units) or sieverts (SI units).
dosimeter	A small portable instrument (such as a film badge, thermoluminescent, or pocket dosimeter) for measuring and recording an individual's total accumulated dose.
dose rate	The radiation dose delivered per unit time.
gamma radiation	High-energy, short wavelength, electromagnetic radiation emitted from the nucleus of an atom. Gamma rays are very penetrating and are best stopped or shielded by dense materials, such as lead, tungsten, or uranium. Gamma rays are similar to x-rays but are usually higher in energy.
giga- (G)	A prefix that indicates multiplying a basic unit by a billion (1,000,000,000 or 10^9).
gray (Gy)	The international system (SI) unit of radiation dose expressed in terms of absorbed energy per unit mass of tissue. The gray (Gy) is the unit of absorbed dose and has replaced the rad. 1 gray = 100 rads

half-life	The time in which one half of the atoms of a particular radioactive substance disintegrate into another nuclear form. A measured half-life may vary from millionths of a second to billions of years. Also called physical or radiological half-life, as opposed to biological half-life, which is the time period required for a living organism to remove half of a chemical substance from the organism.
health physics	The science concerned with the recognition, evaluation, and control of health hazards to permit the safe use and application of ionizing radiation.
ionizing radiation	Radiation with enough energy to eject electrons from atoms and, hence, break chemical bonds.
isotope	One of two or more atoms with the same number of protons, but different numbers of neutrons in their nuclei. Thus, Carbon-12, Carbon-13, and Carbon-14 are isotopes of the element carbon.
isotope identifier	Radiation detection equipment that is used to identify the specific radionuclide or radionuclides present as a radiation source in or on a person or shipment. (See also radioactive isotope identification device).
kilo- (k)	A prefix that indicates multiplying a basic unit by a thousand (1,000 or 10^3).
mega- (M)	A prefix that indicates multiplying a basic unit by a million (1,000,000 or 10^6).
micro- (μ)	A prefix that indicates dividing a basic unit by one million (equivalent to multiplying by 10^{-6}).
milli- (m)	A prefix that indicates dividing a basic unit by 1,000 (equivalent to multiplying by 10^{-3}).
nano- (n)	A prefix that indicates dividing a basic unit by one billion (equivalent to multiplying by 10^{-9}).
natural uranium	Uranium as found in nature, consisting of 0.72 percent by weight of Uranium-235, 99.28 percent Uranium-238, and a trace of Uranium-234. The presence of natural uranium is often confirmed on an isotope identifier when both Uranium-235 and Uranium-238 are identified as present in the material.

neutron	An uncharged ("neutral") elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen. The neutron is very penetrating because it is uncharged but will interact with surrounding materials, especially hydrogen, by direct collisions. The neutron is generated by spontaneous fission of Plutonium-240 (a contaminant found in plutonium), by cosmic-ray spallation, and by nuclear interactions of alpha particles with light elements, such a beryllium.
nuclide	A general term that refers to any known isotope, either stable or unstable, of any element. A single element can have isotopes, but when referring to the isotopes of more than one element, the proper term is nuclide. A radionuclide is an unstable nuclide.
pico- (p)	A prefix that indicates dividing a basic unit by one trillion (equivalent to multiplying by 10^{-12}).
plutonium (Pu)	A heavy, radioactive, man-made metallic element with atomic number 94. Its most important isotope is the fissile Plutonium-239. It only exists naturally in trace amounts in uranium ores. A common contaminant is the neutron-emitting Plutonium-240. Weapons-grade plutonium contains less than 6% Plutonium-240.
personal radiation detector (PRD)	A small detection instrument worn by an individual that directly measures the ionizing radiation exposure.
quality factor	A multiplication factor to convert from absorbed dose (rad or gray) to effective dose (rem or sievert). The factor is typically 1 for beta particles and gamma rays, but is larger for alpha particles (X20) and for neutrons (the factor is dependent on neutron energy).
rad	The unit for absorbed dose. The rad has been replaced by the gray in the SI system of units. 100 rad = 1 gray

radiation source	Usually, a sealed source of radiation used in medical or industrial applications.
radiation standards	Legislative or regulatory means established for the safe use, handling, and application of ionizing radiation. The term is also used synonymously with radioactive calibration sources.
radioactive material	Any material that spontaneously emits ionizing radiation. However, regulatory definitions often establish an activity threshold for a uniformly distributed material to be termed radioactive material. For example, 74 Bq per gram (0.002 μCi/g or 2 nCi/g) is the specific activity provided in the U.S. Code of Federal Regulations (49CFR173.389[e]) for determining what material qualifies as radioactive material.
radioactivity	The level of a radioactive material expressed as the number of atoms that will decay per second. The unit for the number of decays per second is the becquerel (Bq). Other common units and their conversions: 1 Bq = 60 disintegrations per minute (dpm) 1 Curie (Ci) = $3.7\text{x}10^{10}$ Bq
radiological dispersal device (RDD)	An RDD is a mechanism for the dispersion of radioactive material to cause contamination and radiation exposure, along with economic damage. An RDD is not a nuclear weapon.
radium (Ra)	A radioactive metallic element with atomic number 88. As found in nature, the most common isotope has a mass number of 226. It occurs in minute quantities associated with uranium in pitchblende, carnotite, and other minerals.
radon (Rn)	A radioactive element that is one of the heaviest gases known, with atomic number 86. It is a daughter of radium and has a 3.8-day half-life. Radon is chemically inert, being a noble gas, so will often escape into the atmosphere if the parent radium is close to an exposed surface.

rem (roentgen equivalent man)	A unit in the traditional system that measures the effects of ionizing radiation on humans. 1 rem = 1,000 millirem The rem and millirem (mrem) provide a means of communicating the biological damage or health risk to our bodies.
radioactive isotope identification device (RIID)	A radiation detection device that analyzes the energy spectra of the suspect item to identify the isotope.
safety zone	A perimeter established around a radiation source (actual or suspect) to minimize dose to workers and members of the public (during secondary procedures).
shielding	Any material or obstruction that absorbs radiation and thus tends to protect personnel or materials from the effects of ionizing radiation or hides radioactive material from detection.
sievert (Sv)	The international system (SI) unit for dose equivalent. The sievert has replaced the rem. The sievert represents a very large dose since 6 Sv is a lethal dose when administered within a week or two. More common representations are the millisievert and microsievert. 1 Sv = 100 rem
special nuclear material (SNM)	As defined under the U.S. Atomic Energy Act of 1954, SNM is plutonium and uranium enriched in the isotope Uranium-235 or the man-made isotope Uranium-233.
survey meter	Any portable radiation detection instrument (analog or digital) for inspecting an area or individual to establish the amount of radiation or radioactive material present.
uranium	A radioactive element with the atomic number 92. The two principal natural isotopes are Uranium-235 (0.720 percent of natural uranium), and Uranium-238 (99.2745 percent of natural uranium along with Uranium-234 (0.0055 percent).
weapons of mass destruction (WMD)	A nuclear, chemical, biological, or missile system capable of causing significant death, destruction, and terror.

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Appendix C: Radiological Health Information

Radiological Exposure Guidance

The primary concern after an alarm is triggered is to protect the general public and response personnel from unnecessary radiation exposure so that the dose received is maintained as low as reasonably achievable.

Radiation Protection

Sources of radiation from natural background and man-made materials and devices contribute to our annual exposure to radiation. Many studies are conducted to determine average annual doses. For example, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) regularly publishes data on doses from all sources. The latest review, published in 2000, estimates an average worldwide dose of 2.8 mSv from all sources. The U.S. average is 3.6 mSv. Over 82 percent of this total is from natural sources, of which over half comes from natural radon decay products. Medical exposures account for the remaining 14 percent.

Natural Background Sources

Natural background sources include:

- Cosmic Radiation
- Terrestrial Radiation
- Internal Radiation

Cosmic Radiation

The earth, and all living things on it, is constantly bombarded by radiation from space, similar to a steady drizzle of rain. Charged particles from the sun and stars interact with the earth's atmosphere and magnetic field to produce a shower of ionizing radiation. The dose from cosmic radiation varies in different parts of the world due to differences in elevation (high elevations have less atmospheric shielding) and the effects of the earth's magnetic field. Pilots and flight attendants receive more dose than the general public and travelers on polar-route flights experience more dose than travelers on equatorial-route flights.

Terrestrial Radiation

Radioactive material is found throughout nature, occurring naturally in soil, water, and vegetation, and commonly found in building materials. The major isotopes of concern for terrestrial radiation are uranium and thorium and their decay products such as radium and radon. Low levels of uranium, thorium, and their decay products are found everywhere. Some of these materials are ingested with food and water, while others, such as radon, are inhaled. The dose from terrestrial sources varies in different parts of the world. Locations with higher concentrations of uranium and thorium in their soil have higher dose levels.

Internal Radiation

In addition to external radiation sources, such as cosmic and terrestrial sources, all living organisms also contain internal sources of radiation, such as potassium, which is essential for life. The source of ionizing radiation in potassium is a minor isotope, Potassium-40, which accounts for 0.0117% of normal potassium. The amount of potassium in an average human yields between 2000 and 6000 disintegrations per second. Also present in the body are the naturally occurring radioisotopes Lead-210 and Carbon-14, and other radioisotopes inside our body from birth. The variation in internal dose from one person to another is not as great as the variation in dose from cosmic and terrestrial sources.

Man-Made Radiation Sources

Although all living things are exposed to natural background radiation, two distinct groups are exposed to man-made radiation sources. These two groups are:

- Members of the public
- Occupationally exposed individuals

Members of the Public

Man-made radiation sources that result in exposure to members of the public include:

- Medical x-rays—up to 11% of the average human annual dose
- Nuclear medicine—up to 4% of the average human annual dose
- X-rays generated while watching television—up to 3% of the average human annual dose
- Smoke detectors—less than 0.3% of the average human annual dose
- Lantern mantles—less than 0.1% of the average human annual dose
- Operation of nuclear power plants—less than 0.1% of the average human annual dose
- Fallout from aboveground testing of nuclear weapons—less than 0.3% of the average human annual dose

By far, the most significant source of man-made radiation exposure to the public is from medical procedures, such as diagnostic x-rays, nuclear medicine, and radiation therapy. Some of the medical isotopes include Iodine-131, Technicium-99m, Thallium-201, and others.

In addition, members of the public are exposed to radiation from consumer products, such as the radon decay-product Polonium-210 (found in tobacco), building materials, combustible fuels (natural gas, coal, etc.), ophthalmic glass, televisions, luminous watches and dials (tritium), airport x-ray systems, smoke detectors, road construction materials, electron tubes, fluorescent lamp starters, lantern mantles, etc.

The final sources of exposure to the public would be shipment of radioactive materials and residual fallout from nuclear weapons testing and accidents, such as Chernobyl.

Occupationally Exposed Individuals

Occupationally exposed individuals work in the following environments:

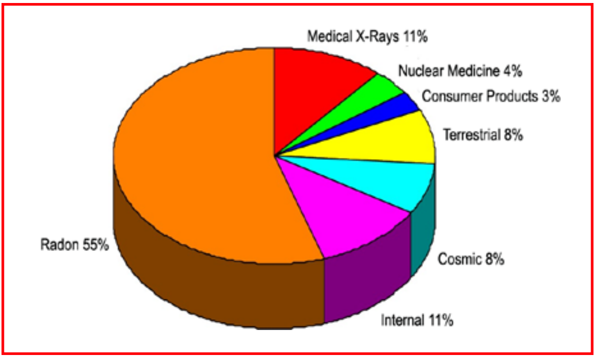
- Industrial Radiography
- Radiology Departments (Medical)
- Radiation Oncology Departments
- Nuclear Medicine Departments
- Nuclear Power Plants
- National (government) and University Research Laboratories

Individuals are exposed according to their occupations and to the sources with which they work. The exposure of these individuals to radiation is carefully monitored with the use of dosimeters.

Ionizing Radiation Exposure to the Public

The following chart shows that for a total dose of about 3.6 mSv/year (~10 μSv/day or ~1 mrem/day), natural sources of radiation account for about 82% of all public exposure, while man-made sources account for the remaining 18%. Natural and artificial radiations are not different in any kind or effect. Some additional exposure to ionizing radiation above these natural background levels is allowed. Common international regulations require that licensees limit maximum radiation exposure to individual members of the public to 1 mSv per year (100 mrem/yr) and limit occupational radiation exposure to adults working with radioactive material to 50 mSv per year (5000 mrem/yr = 5rem/yr).

Man-Made Radiation Sources	**Natural Radiation Sources**	**Other**
Medical X-Rays	Radon	Occupational 0.3%
Nuclear Medicine	Internal	Fallout <0.3%
Consumer Products	Terrestrial	Nuclear Fuel Cycle 0.1%
Other	Cosmic	Miscellaneous 0.1%
Total of 18%	*Total of 82%*	*Total of <1%*



Effects of Radiation

Radiation causes ionizations in the molecules of living cells. Ionization results in an electron being ejected from an atom or molecule, forming a charged atom or ion. The ion thus formed may further react with another atom or molecule in a living cell, causing damage. An example of this would be a gamma ray passing through a cell that ionizes a water molecule near the DNA; the water ion might then react with the DNA, causing it to break.

At low doses, such as what we receive every day from background radiation (~10 μSv/day or ~1 mrem/day), the cells repair the damage rapidly. At higher doses (up to 1000 mSv or 100 rem), the cells might not be able to repair the damage, and the cells may either be changed permanently or die. Most cells that die are of little consequence, the body just replaces them. However, some cells changed permanently might go on to produce abnormal cells when they divide. Under the right circumstance, such cells might become cancerous. This is the origin of our increased risk in cancer as a result of radiation exposure.

At even higher doses, the cells cannot be replaced fast enough and tissues fail to function. An example of this would be "radiation sickness." This is a condition, typically nausea and vomiting, that results after high acute doses to the whole body (2000 mSv or 200 rem), the body's immune system is damaged and cannot fight off infection and disease. Several hours after exposure nausea and vomiting occur, followed by diarrhea and general weakness. With higher whole body doses the effects become progressively more damaging and more immediate. Above 4500 mSv (450 rem) if no medical attention is given, about 50% of the people are expected to die within 60 days (also known as the LD50). Although exposure to ionizing radiation carries a risk, it is impossible to completely avoid exposure. Radiation has always been present in the environment and in our bodies.

Effects of Acute Gamma-Radiation Exposure

Acute Whole Body Dose (Sv)	Acute Whole Body Dose (mSv)	Acute Whole Body Dose (rem)	Biological Effects
0–0.05	0–50	0–5	No immediate observable effects.
.02	20	2	IAEA limit for annual occupational exposure.
.05	50	5	US Legal limit for annual occupational exposure.
.5	500	50	Slight blood changes. Possible fatigue and nausea.
1	1000	100	Possible vomiting.
1.5	1500	150	Highly probable survival.
4.5	4500	450	LD50—50% of those exposed within 30–60 days without medical treatment.
8	8000	800	Nausea within hours—probable death in 1–2 weeks.
20	200	2000	Central nervous system damage leading to loss of coordination—death certain within 2–5 days.

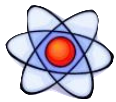
Appendix D: Major Isotopes of Concern and Common Innocent Radiation Sources

Isotopes of Major Concern

SNM is defined by the U.S. Atomic Energy Act of 1954 and others as being capable for use in nuclear weapons and includes:

- Plutonium
- Uranium enriched in Uranium-235
- Uranium-233
- Neptunium-237
- Americium

Common Natural and Commercial Sources of Gamma Radiation



Medical Isotopes

These might be in injected into a person's bloodstream as part of a medical diagnostic procedure or implanted as pellets for a therapeutic procedure. Someone who has received a nuclear medical treatment within the past few weeks might trigger a radiation alarm. Radionuclides used for diagnostic procedures typically emit gamma rays that can be used for identification. However, radionuclides used for therapeutic procedures often emit only beta particles and may not allow for identification. Common medical isotopes include:

- Gallium-67 — Spleen and red marrow diagnostics
- Iodine-131 — Thyroid and kidney diagnostics
- Indium-111 — Liver, kidney, spleen diagnostic imaging
- Technicium-99m — Most common radiopharmaceutical
- Thallium-201 — Heart and lung diagnostic imaging
- Xenon-133 — Radioactive inert gas for lung-function diagnostics

Less-common medical isotopes include:

- Germanium-68
- Iodine-123
- Iodine-125
- Palladium-123
- Samarium-153
- Strontium-82
- Strontium-85
- Yttrium-90
- Zinc-65

Items and Products that may Contain Radioactive Materials

- Agricultural products (e.g., fruits and leafy vegetables, tobacco, marijuana, etc.)—Polonium-210 and Bismuth-210
- Bananas (large quantities)—Potassium-40
- Antique items including:
  - Ceramic-glaze products in orange, red, or white (cups, plates, saucers, pottery, etc., especially "Fiestaware")—uranium, natural or depleted
  - Vaseline-glass items (fluorescent yellow or emerald green glass used in some antique cups, plates, Czech bead jewelry, etc.)—uranium, natural or depleted
- Camera lenses and many high-quality optical lens system—thorium in the glass
- Radio-luminescent products (radium paint): watches, clocks, and instrument gauges—radium, Promethium-147, tritium
- Porcelain dental ceramics—Uranium-234 (very low dose)
- Lantern mantles—natural thorium
- Polishing powders—thorium contaminant in the cerium abrasive
- Propane tanker trucks—from Lead-210 and Bismuth-210 (radon decay products) deposits on the tanker's interior walls
- Smoke detectors—Americium-241
- Television sets—thoriated tungsten in the cathode-ray picture tubes
- Thoriated aluminum, nickel, or magnesium—high-tech alloys containing thorium
- Thoriated-tungsten arc-welding electrodes—often labeled thoriated welding rods and color-coded orange for 4% thorium, red for 2%, and yellow for 1%
- Uranium ore samples—uranium if freshly separated, radium if unseparated

Common NORM (Emits Gamma Rays, Beta Particles, and Alpha Particles)

- Potassium (K-40)—Gamma rays and beta particles
- Radium (Ra-226)—Gamma rays, beta particles, and alpha particles
- Thorium (Th-232)—Gamma rays, beta particles, and alpha particles
- Uranium (U-238)—Gamma rays, beta particles, and alpha particles
- Some other materials that often contain NORM:

  - Granite
  - Concrete
  - Monazite sand
  - Feldspar
  - Sandstone
  - Fertilizers
  - Slate
  - Colored marble

Sources Commonly Used in Industry (May Be of Concern if Misused)

- Americium-241
- Barium-133
- Cesium-137
- Cobalt-57
- Cobalt-60
- Iridium-192
- Radium-226
- Thorium-232

Industrial radiography source capsule, used to contain approximately 0.1 curie of Radium-226.

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Gamma-emitting industrial radiography sources, used to "x-ray" thick metal and reach confined areas. A small metal capsule at one end of a flexible cable houses 30 to 100 curies of Iridium-192 or Cobalt-60.

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Source capsule used in medical teletheraphy units. The gamma rays from its Cobalt-60 or Cesium-137 source were used to treat cancer.

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Common Commercial Neutron Sources and Isotopes

Moisture- and soil-density gauges, asphalt-thickness gauges, and well-logging equipment often contain neutron sources.

- Californium-252—spontaneous fission neutrons
- Americium/Beryllium—AmBe (alpha, neutron) source
- Polonium/Beryllllium—PoBe (alpha, neutron) source
- Plutonium/Beryllium—PuBe (alpha, neutron) source

Isotopes of concern for RDDs.

- Cobalt-60
- Iridium-192
- Cesium-137
- Strontium-90
- Americium-241
- Radium-226
- Plutonium
- Californium-252

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Handbook for
Response to Suspect Radioactive Materials

U.S. DEPARTMENT OF ENERGY

NNSA
National Nuclear Security Administration