



Competency 1.9 Radiation protection personnel shall demonstrate a familiarity level knowledge of radiological hazards associated with the following:

- **Plutonium operations**
- **Uranium operations**
- **Tritium operations**
- **Nuclear explosive operations**
- **Production/experimental reactors**
- **Accelerator operations**
- **Waste handling/processing operations**
- **Decontamination and decommissioning**
- **Use of radiation-generating devices**
- **Environmental restoration activities**

1. SUPPORTING KNOWLEDGE AND /OR SKILLS

- a. Discuss the basic function and work activities associated with the above list.
- b. Discuss fundamental characteristics of the major radiological hazards at the above listed activities. This could include discussion of:
 - Mode of decay
 - Source
 - Energies of major radiations emitted
 - Relative principle biological hazard
 - Half-life
- c. Discuss unique radiological exposure control techniques associated with the above listed activities.



2. SUMMARY

Plutonium Operations

Function

In the past, most Plutonium (Pu) was used as the fissile material for nuclear weapons. The isotope used in the production of nuclear weapons was Pu-239, a fissile material, which fissions upon absorption of a thermal neutron. Pu-239 could also be used in a reactor fuel for the production of electrical power. The isotope, Pu-238 is used as heat sources and thermoelectric generators for missile and satellite applications. A potential use of plutonium is to power medical prosthetic devices such as cardiac pacemakers and artificial hearts.

Plutonium can be particularly hazardous because it can be an/a:

- Internal radiation hazard from alpha emissions
- Pyrophoric hazard, pieces of the metal can spontaneously ignite when exposed to moist air
- Criticality hazard, as little as 500 grams (g) of Pu-239 in solution can achieve criticality.

Work Activities

Work activities include both production and processing facilities. Plutonium production reactor operated at Hanford and Savannah River. Between 1944 and 1988, the U.S. built and operated 4 plutonium production reactors at Hanford and Savannah River producing approximately 100 metric tons of plutonium. Hanford had nine reactors, all had large cubes of graphite blocks with horizontal channels cut in them for uranium fuel and cooling water. The fuel slugs were inserted into the front face of the reactor, went through neutron bombardment, pushed through the channels gradually, and fell out the other side. Savannah River consisted of five reactors, with large tanks of "heavy water," where highly enriched fuel and separate depleted uranium targets were submerged. Only a small fraction of uranium was converted to plutonium during each cycle through a reactor.

At Hanford, uranium-238 (U-238) was exposed to a neutron flux creating U-239, which quickly decays by beta emission to neptunium-239 (Np-239), which beta decays to Pu-239. After a sufficient irradiation period, the plutonium is then extracted from the fuel rods and sent to a processing facility. The production process creates tremendous amounts of high-level waste, which is currently stored in tanks at the Hanford site. (The N-reactor at Hanford was built during the 60s and was the focus of intense review. It was shut down in 1987.)

The bulk plutonium is then sent to a processing facility. Massive or bulk plutonium is relatively inert in dry air and is comparatively easy to handle and store for a few days. But, a significant amount of work with plutonium dealt with machining the raw metal into bomb components. The machining process



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created fine powders and metal turnings, which are pyrophoric. This process was mainly done in glove boxes inerted with nitrogen or argon to prevent fires. (Metal turnings must not be stored and should be converted to oxide as soon as possible.) The oxidation of plutonium does not always occur in a predictable manner because the oxidation rate is a complex function of the surrounding atmosphere, the moisture content, and the alloys or impurities present in the metallic plutonium. Plutonium metal components for weapons were machined at Rocky Flats, but due to a number of glove box fires, exposure to a DOE inspector and two employees, and the cancellation of W-88 warhead (a Rocky Flats major project), plutonium manufacturing operations were shut down and the mission was redefined to Decommissioning & Decontamination, waste clean up and environmental restoration. Because of the sudden shut down of plants that did plutonium operations, 26 tons of plutonium were stranded in various intermediate steps. Currently in the U.S., if plutonium is not in operational warheads, it is stored at facilities across the country. In 1989, a National Academy of Sciences panel concluded that additional plutonium production was unnecessary. However, the plutonium surplus continues to increase as each day more plutonium is removed from dismantled weapons at the Pantex Plant in Texas at a rate of approximately 2,000 warheads per year.

Radiological Hazards

Predominant Radionuclides/Sources

Transuranics are the predominant radionuclides at most plutonium facilities. Plutonium isotopes include Pu-238, Pu-239, Pu-240, Pu-241, Pu-242. Both physical and chemical means are used to separate and enrich Pu-239 for weapons grade material which ends up about 90% by weight of Pu-239 and 6 to 8 % Pu-240. The exact amount and ratios of radionuclides in a given sample depends on the length of time since separation.

Radionuclide	Decay Mode	Decay Energy (MeV)	Half-life	Biological Hazard
Pu-236	alpha	5.7	2.85 years	bone surface
Pu-238	alpha	5.5	87.7 years	bone surface
Pu-239	alpha	5.1	24,000 years	bone surface
Pu-240	alpha	5.1	6,500 years	bone surface
Pu-241	beta	0.0052 average	14.4 years	bone surface
Pu-242	alpha	4.9	423 years	bone surface

Plutonium isotopes have a biological clearance half-life of about 200 years for bone tissue. Bone seekers have extremely long retention times after incorporation into bone tissue.

Exposure Control Techniques



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Exposure control techniques should include both administrative and physical controls. Administrative controls include the use of radiation work permits (RWPs) to authorize exposures. Other administrative controls include the use of procedures and trained personnel. Procedures should require strict contamination control by using good housekeeping practices verified by routine surveys, the posting of contamination areas, the use of protective clothing, and routine personnel monitoring. Housekeeping should include an inventory of plutonium materials at the source to prevent the spread of contamination. In order to prevent the spread of contamination and intakes of plutonium, containments such as glove boxes are used. Glove boxes are usually kept at a negative pressure with respect to the surrounding area so air leaks into the containment, preventing contamination from leaking out. The type and extent of control measures used in radioactive work will vary. For example, in some cases, plutonium is handled in open-faced hoods, but in most instances it is handled in semi-remote units (glove boxes) or remote enclosures (hot cells).

Features of a particular handling operation may dictate special control measures, as does the state of the plutonium being used. For example, low levels ($< 37 \text{ kBq}$ ---approximately $1 \text{ } \mu\text{Ci}$) of nondusty plutonium samples does not require the degree of control that higher levels do. Sealed or clad plutonium, regardless of amount, may be handled in hoods rather than glove boxes for certain steps in a process.

The laboratory handling of plutonium often differs from that found in a plant or production facility. In general, up to 0.2 GBq (approximately 5 mCi) of plutonium may be handled in open hoods; glove boxes are used for larger amounts. In plants in which gram or kilogram amounts are used, glove boxes are used almost exclusively. Dusty operations or for plutonium in other pyrophoric forms call for the use of glove boxes with inert atmospheres.

In processes involving highly radioactive materials, such as irradiated plutonium samples that have not been separated from fission products, hot cells are used to provide shielding. Appropriate combinations of construction materials are used to provide protection from penetrating radiation (gamma and neutron). Hydrogenous materials, such as concrete and oil, are used to shield neutron radiation; while dense materials, such as lead and steel, are used to shield gamma photons. Viewing ports are constructed of leaded or oil-filled glass (or other substances) to minimize dose rates.

DOE/EH-0425, *Plutonium Facilities Training Material*, includes more detailed information on plutonium history, isotopes, uses and properties, internal and external hazards, modes of exposure and treatment, radiological controls, surveys and monitoring at plutonium facilities, and response techniques for abnormal conditions. The student manual to this course can be downloaded from the following web page:

<http://tis-nt.eh.doe.gov/WPPHM/RST/rst.htm>

The learning objectives of the manual include: characteristics, grades and isotopes of plutonium; their respective physical, chemical, reactive, radioactive and criticality properties; radiological properties; modes of entry and removal techniques; control methods; identification and monitoring techniques



detection and dosimetry.

Uranium Operations

Function

Natural uranium consists of three isotopes: uranium-238 (U-238), uranium-235 (U-235), and uranium-234 (U-234). U-238 is 99.284 percent abundant in nature with a half life of 4.46 billion years; U-235 is 0.711 percent, and half life of 704million years; U-234 is 0.0055 percent, and half life of 245,000 years. U-238 decays by alpha emission intothorium-234, which itself decays by beta emission to protactinium-234, which decays by beta emission to U-234, and so on until theseries ends with the stable isotope lead-206.

Uranium is important to the nuclear industry primarily because of the naturally occurring isotope U-235, which has a high thermal fission cross section. To increase the amount of U-235 in a reactor core, and to decrease the size of a reactor, natural uranium is enriched in U-235 by special processes such as a gaseous diffusion, centrifuging, or laser separation. Natural uranium depleted in U-235 is also useful as shielding, counterweight, projectiles, and target elements in DOE plutonium production reactors.

As previously stated, natural U-238 is found in 99% abundance in nature. From this, the remaining 0.7% of U-235 must be physically separated in sufficient quantitiesfor nuclear fuel, or for explosives. Gaseous diffusion is the process used in the U.S. for the enrichment ofuranium. Gaseous diffusion is when U-238 is driven at controlled temperatures and pressures through miles of filters which gradually collect U-235 atoms in increasing concentration. Highly enricheduranium is considered more than 20% U-235, and low enrichment uranium consists of less than 20%. Typically more than 90% U-235 is used in nuclear weapons. U-238 removed during enrichment is referred to as "depleted uranium." Thousands of tons of depleted uranium are stored in cylinders in Ohio, Tennessee and Kentucky.

One ton of uranium ore yields only a few pounds of uranium metal. The result is a dry concentrate called "yellowcake." The milling process produces large volumes of sandlike by-product, mill tailings. Mill tailing contains toxic heavy metals and radium and thorium. Uranium mill tailings account for only a small fraction of the total radioactivity, but approximately 96% of the total volume. The primary hazard associated with uranium mill tailings is radon gas.

Work Activities

Much of the uranium feed material that is currently handled at DOE facilities has been reclaimed and recycled from reprocessed spent reactor fuel. The chemical processes by which recycled uranium is purified release trace amounts of transuranic elements and fission products, mainly technetium-99 (Tc-99). Recycled uranium also contains trace amounts of uranium isotopes not found from fuel reprocessing facilities, but the radiological impact of these impurities is negligible in many cases. There



are many routine chemical processes which tend to concentrate these impurities either in the uranium product or in reaction by-products such that radiological controls and/or environmental monitoring programs must consider these impurities in some cases.

It is anticipated that the amount of recycled uranium will increase over the next several years. This is due to the plans of a number of nations to reprocess uranium for their power reactors.

Radiological Hazards

The radiological hazard present from uranium depends on the processes conducted at the facility. Categories of uranium may include:

- Natural uranium
- Decay chain daughters
- Recycled uranium
- ²³⁵-enriched uranium

Natural Uranium

Natural uranium consists of three primary isotopes U-238, U-235, and U-234. The primary isotopes of uranium are all long-lived alpha emitters. U-235 also decays by gamma emission. The principal radiological hazard is from inhalation of airborne uranium. Uranium is both a chemical and radiological hazard. For natural uranium, chemical toxicity is usually more limiting. All three isotopes have somewhat restrictive annual limit on intake (ALI) values of one microcurie (μCi).

Decay Chain Daughters

Since DOE facilities do not routinely process uranium ore concentrates, the only non-uranium members of these decay chains that will be present in virgin (not recycled) feed materials, which are those that have grown in since the chemical extraction of the uranium.

The primary uranium decay products decay by beta emission. Consequently, the inhalation hazard associated with these nuclides is usually overshadowed by the alpha-emitting uranium isotopes. The nuclides that occur in sufficient abundance to have an impact on radiological control are thorium-234 (Th-234), protactinium-234m (Pa-234m), and Th-231. The long half-lived Th-230 (75,400 years) in the U-238 decay chain and Pa-231 (32,800 years) in the U-235 chain effectively prevent the accumulation of significant quantities of other decay products. Still, Th-230 and radium-226 (Ra-226) may be found in the process waste water of some facilities, so it is prudent to include those nuclides in effluent/environmental monitoring programs. For workplace radiological controls, Th-234, Pa-234m, Th-231, and the uranium isotopes are those requiring primary consideration. In poorly ventilated areas where



uranium is stored, elevated radon (Rn) concentrations can occur from the small amounts of Ra-226 which both grow in and carry over as a contaminant in the chemical separation processes.

Recycled Uranium

The five primary isotopes of concern from recycled uranium are Tc-99, U-232, neptunium-237 (Np-237), Pu-238 and Pu-239. Tc-99 tends to deposit within enrichment equipment and will pocket in the higher enrichment sections of the gaseous diffusion process. In equipment with accumulations of Tc-99, soft beta radiation fields of a few rad per hour may be encountered. This radiation is effectively attenuated by the protective clothing required for contamination control. Since the ALI for Tc-99 is higher than that of uranium, inhalation is a concern only in situations where the technetium activity greatly exceeds that of the uranium that is present. Technetium as pertechnetate is also difficult to remove from skin, which can result in skin contamination and significant skin doses.

The uranium isotopes that will increase in recycled uranium are U-232, U-234, and U-236. U-236 will not pose much of a concern from a health and safety standpoint because it is similar to natural uranium. Conversely, U-232 can be problematic. The health hazards of U-232 are due primarily from gamma activity of its decay products (Th-228). The major exposure from U-232 will be from handling UF₆ cylinders. The exposure is determined by the enrichment of U-235. Exposure rates of 100 to 50 mrad/hr could exist.

Transuranics neptunium and plutonium will exist in small quantities in recycled material. However, they can cause significant internal dose even at very low mass concentrations. For example, for a Class W transportability mixture, if Pu-239 contamination contributes 0.1% of the total alpha activity in uranium, then it will contribute roughly 14% of the total inhalation dose equivalent because of its lower ALI.

235-Enriched Uranium

Uranium presents both a chemical and radiological hazard. The primary hazard associated with uranium depends upon its degree of enrichment, its chemical form, and its physical form. The degree of enrichment determines the gamma radiation intensity and the overall specific activity. The chemical form determines solubility and consequently transportability in body fluids. The transportability of an inhaled or ingested material determines its fate within the body and, therefore, the resulting dose or chemical effect. When radiological hazards are limiting, chemical hazards can generally be neglected except in overexposure situations. When chemical hazards are limiting, radiological hazards can be neglected if radiation doses are below regulatory concern. Uranium is toxic to the kidneys and high exposure of soluble compounds can result in renal injury.

Neutron doses can also be a concern as enrichment in U-235 increases. Alpha radiation emitted from uranium can create an (α , n) reaction with fluoride (F) and other low Z atoms. The neutron energy is in the 2 MeV range. In the case of UF₆ the typically measured neutron dose rates for cooled storage



cylinders are as follows:

Natural to 5% enrichment: 0.01 to 0.2 mrem/hr

High enrichment (97%): 2 to 4 mrem/hr or contact and 1 to 2 mrem/hr at 3 feet

Radionuclide	Decay Mode	Decay Energy (MeV)	Half-life	Biological Hazard
U-238	alpha	4.2	4.5x10 ¹⁰ years (y)	bone surface
U-235	alpha	4.4	7x10 ⁸ y	bone surface
U-234	alpha	4.7	2.46x10 ⁵ y	bone surface
Th-234	beta	0.193	24 days	whole body
Pa-234m	beta	2.3	1.2 min	skin, extremity
Th-231	beta	0.305	25.5 hours	whole body

U-234 is concentrated with U-235 during the enrichment process. Highly enriched uranium contains approximately 1% U-234. Because of its much shorter half-life, most of the radioactivity of enriched uranium comes from U-234.

ALARA Techniques

Development and implementation of an (ALARA) program in many uranium facilities may be a challenging task, due primarily to the fact that penetrating radiation doses are typically low and few individuals are exposed near the regulatory limits for occupational exposures. As a result, convincing management to spend valuable funds to further reduce radiation exposures to ALARA can be a problem. An ALARA program can be defined in four major elements: 1) program administration, 2) goal setting and program evaluation, 3) radiological design, and 4) conduct of operations. All four elements are vital to the successful implementation of ALARA.

Program Administration

Not only is management commitment to the concept and success of the ALARA program important, but communication to all employees is essential. Policy statements, procedures, and manuals, as well as direct communications, should be used to ensure that facility employees are aware of:

- a. The program
- b. Their personal responsibility
- c. Their role in its success



d. Personal benefits of the program

Goal Setting

Goals for the ALARA program may be either quantitative or nonquantitative and may or may not be related to dose measurement. All goals, however, should have one or more clearly defined end points which contribute directly or indirectly to reducing personnel exposures. An ALARA committee composed of representatives from operations, engineering, radiation protection, and others responsible for the ALARA program can often establish more effective goals than any one special interest group. In addition to the ALARA program evaluation, routinely performed as a function of management of the program, an independent evaluation should be conducted periodically. The evaluation should be commissioned by senior management and the personnel conducting it should report directly to them. A formal report should be issued to senior management and include an overall assessment of the program, findings of the evaluation, areas of strengths and weaknesses, and recommendations for change and improvement.

Design of facility features, to accommodate anticipated presence of radioactivity or radiation-generating devices (RGDs), is important in reducing radiation doses received in the conduct of work with radioactive materials to ALARA. For both new facilities and the modification of existing facilities, ALARA considerations should be introduced into the design process at the earliest possible stage. Some of the design features that relate to the successful realization of ALARA objectives are:

- The layout of the facility; specifically, the use of sequential radiation or contamination zones and the control of traffic patterns
- The ventilation system, which should use pressure differentials and high-efficiency particulate air (HEPA) filters to trap airborne radionuclides and prevent the spread of airborne contamination within, or from, the facility
- The waste removal systems, which should minimize the amount of radioactive waste material permitted within a facility; provide storage and handling to control exposure of personnel to casual doses; and minimize the potential for fires, spills, and leakage

Conduct of Operations

The application of the ALARA principles to the performance of work in the field is the main objective of conduct of operations. ALARA design, engineering, planning, and administration come to fruition in maintaining radiation exposures to workers and the public ALARA. The operational application of ALARA requires the cooperation and coordination of many functional groups including radiation protection, operations, maintenance, planning and scheduling, training, engineering, and administration.

The primary responsibility for controlling radiation exposure during operations rests with the individual



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and his/her immediate supervisor. The support functions provide the training, resources, guidance, and measurements; but it is in the application that the effectiveness of the ALARA program may be realized. Operational measures for controlling exposure must be applied to assure that any work with radioactive materials is carried out in the safest manner reasonable. Both engineered and administrative control measures should be used for limiting exposure.

Draft Radiological Safety Training for Uranium Facilities, training manual discusses in greater detail such issues as:

- the nuclear fuel cycle.
- physical, radioactive and chemical properties of uranium.
- external exposure control and measurements.
- internal exposure control and measurements.
- criticality safety.
- emergency response for uranium incidents.

The student manual can be found at the following web site:

<http://tis-nt.eh.doe.gov/WPPHM/RST/rst.htm>

This document contains general information of the following basic concepts: uranium for nuclear reactors; radioactive decay products of uranium; nuclear fission; fissile and fissionable materials; enriched and depleted uranium; uranium isotopes; UF_6 gas; uranyl solutions; uranium toxicity; pyrophoric hazards of uranium; alpha, beta, gamma and neutron monitoring techniques; beta shielding and criticality.



Tritium (H-3) Operations

H-3 is produced by both natural and manmade means. H-3 is produced in the upper atmosphere by cosmic radiation interactions with nitrogen. Once produced, H-3 is carried in rainfall to the surface of earth where it accumulates in the oceans. Atmospheric nuclear tests also added significant amounts of H-3 to the environment. H-3 is produced in light and heavy water reactors, fuel reprocessing plants, and tritium production reactors.

Function

H-3 is the fuel source for fusion reactions which power the hydrogen bomb. H-3 has many laboratory uses such as compound labeling, and may in the distant future be used as a source of fuel for fusion power reactors.

Radiological Hazards

H-3 decays by emitting a weak beta particle, the daughter product is helium-3 (He-3).

Radionuclide	Decay Mode	Decay Energy	Half-life	Biological Hazard
H-3	beta	18.6 keV maximum 5.7 keV average	12.3 years	internal whole body

H-3 is usually encountered in the workplace as H-3 gas (HT, DT, T₂) or as H-3 oxide (HTO, DTO, T₂O). Other forms of H-3 also exist, such as metal tritides, tritiated pump oil, and tritiated gases. These various tritiated compounds have a wide range of uptake and retention in humans under similar exposure conditions. For example, H-3 gas, upon inhalation, is only slightly incorporated into the body and is rapidly eliminated; whereas, tritiated water vapor is readily taken up and retained by the body.

Following a brief exposure to H-3 gas, small amounts of the gas are dissolved in the bloodstream. For gaseous H-3 exposures, there are 2 doses: 1) a lung dose from the H-3 in the air in the lung, and 2) a whole body dose from the H-3 gas that has been converted to water. This tritiated water converted in vivo acts as an exposure to tritiated water.

Skin absorption of gaseous H-3 has been found to be negligible compared to inhalation. Small amounts of H-3 can enter skin through contact with contaminated metal surfaces, which results in elevated organically bound H-3 in tissues and urine.



Control Techniques

ALARA should be apparent in the policy and procedure documents that implement a radiation protection program (RPP) at a site, and should also be incorporated into facility design. Containment and confinement, which includes the use of glove boxes and fume hoods, of tritium should be the major design features for maintaining exposures ALARA. Pressure differentials control the flow of airborne contamination including local and dilution ventilation. Good administrative procedures mean good housekeeping requirements and frequent smear and airborne surveys.

Some of the problems encountered when confining H-3 are due to the physical and chemical properties, which cause H-3 gas to interact in some way with almost all materials. Helium is a monoatomic gas therefore, one mole of diatomic T_2 H-3 gas decays to two moles of He-3 gas. This leads to pressure buildup in sealed vessels. The seals fail and may spread contamination. There are also a number of physical properties that govern how H-3 reacts and migrates through materials; specifically, solubility, diffusion, and permeability.

Solubility

Solubility is a thermodynamic property; therefore, the solubility of H-3 is affected by the temperature. The solubility of H-3 may increase or decrease with temperature depending on the element or compound. Hydrogen gas (including H-3 gas) dissolves to some extent in almost all materials. Hydrogen atoms or diatomic hydrogen molecules and some larger hydrogen bearing molecules dissolve interstitially, i.e., they diffuse into a structure and locate between atoms or molecular framework.

Diffusion

Diffusivity is a kinetic property and is a measure of the speed at which a species diffuses. It is important in calculating the rate at which H-3 migrates through a structure. The migration of hydrogen in most materials is orders of magnitude faster than the migration of other elements. The higher the temperature, the faster the diffusion.

Permeability

Permeability of a gas through materials is a measure of how much gas will migrate through a material wall of given thickness and area over a given time. Permeability (Φ) is the product of the diffusivity (D) and solubility (S).

$$\Phi = \left(\frac{cm^3 (H_2, STP) \times cm(thickness)}{cm^2 (area) \times sec} \right) = D \left(\frac{cm^2}{sec} \right) S \left(\frac{cm^3 (H_2, STP)}{cm^3(material)} \right)$$



The following materials are listed in order of increasing permeability:

- ceramics and graphite
- silica
- nonhydrating metals
- hydrating metals
- polymers

H-3 gas diffuses through glass, especially at elevated temperatures.

The following excerpt is from DOE Handbook DOE-HDBK-1079-94, *Primer on Tritium Safe Handling Practices*. This is a good reference document for more information on the chemical, physical, and biological properties of H-3. H-3 monitoring and emergency response procedures are also introduced. The handbook can be found in its entirety on the following web page:

<http://apollo.osti.gov/html/techstds/techstds.html>

DOE-HDBK-1079-94, PRIMER ON H-3 SAFE HANDLING PRACTICES

Radiological Control and Protection Practices

Airborne H-3

H-3 released to room air moves readily with normal air current. The room or building ventilation systems should be designed to prevent the air from being carried to uncontaminated areas, such as offices or other laboratories where H-3 is not allowed. For that reason, differential pressure zoning is commonly used, and released H-3 is directed outside through the building stack. In some newer facilities where the large quantities of H-3 are being handled, room air cleanup systems are available for emergency use. Following a significant release, the room ventilation system is effectively shut down, the room is isolated, and cleanup of room air is begun.

Secondary Containment

The most important control for preventing a release of H-3 to the room atmosphere is the use of containment around the source of H-3. This containment usually takes the form of a glove box, which is then a secondary containment if the H-3 is already contained within the process plumbing, which is the primary containment. Even if the H-3 is on the outside surface of a piece of equipment and located inside the glove box, through popular usage, the box is still referred to as the secondary containment.

Glove boxes used for H-3 work typically are made of stainless steel or aluminum and use gloves made of butyl neoprene, or Hypalon. Windows are made of glass or Lexan. In order to reduce the amount of H-3 released to the atmosphere, glove boxes where significant quantities of H-3 are handled incorporate detritiation systems that process the glove box atmosphere and remove the H-3. These detritiation systems, including the room cleanup systems mentioned above, convert released HT to HTO and collect the HTO on a molecular sieve for later recovery or burial. Newer systems use metal getters that recover HT without resorting to oxidation. These getters, which can only be used in certain glove box atmospheres, can be heated to release and recover the HT easily.

The atmosphere in the glove box may be air, nitrogen, argon, or helium, depending on the type of activity in the box. Even in boxes with inert gas atmospheres, small amounts of moisture and oxygen exist. Any release of H-3 gas in the box will eventually be converted to the oxide. As a result, the oxide will slowly diffuse through the gloves and



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contaminate their outside surfaces. For that reason, personnel using glove boxes that have had H-3 releases are required to wear one or more additional pairs of disposable gloves when working in the glove box.

Glove box monitors are used to alert personnel of a release in the box and may be used to activate a cleanup system or to increase the rate of the cleanup process. With releases of H-3 in the box, the monitor chamber will eventually develop a memory from contamination, mainly by HTO. Heated monitor chambers are useful in minimizing contamination by HTO.

The relative pressure of the glove box atmosphere is normally kept negative in order to prevent the gloves from hanging outside the box where passersby may brush against them and to prevent H-3 from escaping into the room should a leak develop in the glove box. However, outward permeation of HTO through the gloves and inward permeation of room moisture are not affected by the pressure inside the glove box.

Temporary Enclosures

At times, maintenance or repair work is done on equipment that cannot be moved into a glove box or fume hood and that has a high potential to release H-3. For these activities a temporary box ("tent"), may be constructed over the equipment, and an existing cleanup system installed to process the air. Alternatively, if the H-3 at risk is not significant, the enclosing atmosphere may be purged to the stack. If the enclosure is small, gloves and glove ports may be fitted to the side of the enclosure. For larger enclosures entry may be required. In such cases, personnel must work in air-supplied suits inside the enclosure.

Protection by Local Ventilation

In spite of the greater protection afforded by glove boxes, fume hoods are commonly used at H-3 facilities for handling or storing material with low quantities of H-3 or with low-level contamination. Limits are generally imposed on the quantities used or stored in these hoods.

Fume hoods are also used to protect personnel at the outside door of glove-box pass boxes where materials are passed into and out of the boxes. Ideally, any H-3 released in a hood from outgassing or a leaky container, for instance, is routed to the hood's exhaust duct. However, turbulence may occur at the hood entrance, resulting in backwash and possible contamination of personnel if the face velocity is not adequate for the design of the hood, the activities in the hood, or the local conditions (such as traffic in front of the hood). No hood should be used that has not been thoroughly surveyed and judged acceptable for H-3 use.

For small operations local ventilation is commonly provided at the work site through a flexible ventilation duct ("elephant trunk") directed to the room exhaust system. The exhaust of these ducts is generally directed to the building ventilation exhaust system, which of itself may be adequate to supply the needed air flow for the duct without help from an additional in-line blower. Flexible ducts can provide adequate ventilation during maintenance in a glovebox with a panel removed. In this application, a flexible duct can be connected to a gloveport before the panel is removed, and then the work can proceed safely.

Supplied-Air Respirators

In general, only supplied-air respirators are effective in preventing inhalation of airborne H-3. Two types of air-supplied respirators are available: self-contained breathing apparatus (SCBA) and full-face supplied air masks.

An SCBA, consisting of a full-face mask fed by a bottle of compressed air carried on the worker's back, provides excellent protection against HTO inhalation. Because the mask provides no protection against absorption by most of the skin, the SCBA is normally reserved for emergency use only. The protection factor of 3 or more afforded by the



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SCBA may be adequate for some applications. An SCBA can be used as an added precaution during certain maintenance or operations that experience has shown should not result in the release of significant amounts of HTO. Nevertheless, the potential for exposure is real, and the SCBA gives the worker time to leave the area if necessary before a skin exposure occurs.

Full-face supplied-air masks are also available. Because the air is normally supplied by a fixed-breathing-air system, they are not practical for many emergency situations and, consequently, are not as popular as SCBAs.

Supplied-Air Suits

Because of the inherent disadvantages associated with respirators and other breathing apparatus, supplied-air plastic suits that completely enclose the body are often used by facilities that handle large quantities of H-3. Although they afford reasonably complete body protection, they are slow to don and cumbersome to wear. For these reasons, they are not favored for rescue work where time and mobility are important considerations. For certain maintenance operations outside of glove boxes with a high degree of risk, supplied-air suits may be quite useful.

For H-3 work, supplied-air suits are constructed of materials that have acceptable permeation protection against HTO and provide good tear and abrasion resistance. Because of the closed environment, and the additional background noise caused by the flow of air into the suits, communication between personnel may require special equipment or methods.

Protection from Surface Contamination

Experience at H-3 laboratories has shown that many H-3 exposures to personnel occur as a result of contact with highly contaminate surfaces. Sudden and significant releases of airborne H-3 occur mostly as the less toxic form HT and are quickly detected by portable or strategically placed, fixed H-3 monitors. The result is that the exposure and uptake of airborne H-3 are minimized. (Heavy-water reactors, of course, present a more significant risk of exposure to tritiated water vapor than to H-3 gas.) The presence and degree of contamination may be unknown until measurements are made. Consequently, the importance of routine and special monitoring surveys for surfaces that personnel might contact cannot be overestimated.

Protective clothing worn by workers is one of the most important aspects of an effective health physics program. Because H-3 can be absorbed easily through the skin or by inhalation, personnel protective equipment must protect against both exposure routes. The following paragraphs describe protective measures and equipment.



Protective Clothing

Lab Coats and Coveralls

Lab coats and coveralls (fabric barriers) are worn in most H-3 facilities. Lab coats are routinely worn to protect personal clothing. Coveralls are sometimes worn for added protection instead of a lab coat when the work is unusually dusty, dirty, or greasy. The protection afforded by lab coats and coveralls is minimal (except for short exposures) when H-3 is airborne, but they are more effective in preventing skin contact with contaminated surfaces.

Disposable water-proof and water-resistant lab coats and coveralls have been tested at various laboratories. They are not popular for everyday use because of the cost and excessive discomfort inflicted on the worker. Most facilities prefer using ordinary open-weave fabrics for lab coats and coveralls and using an approved laundry for contaminated clothing. Some facilities have chosen to use disposable paper lab coats and coveralls, exchanging the costs associated with laundry for the costs associated with replacement and waste disposal.

Shoe Covers

Although shoe covers provide protection against the spread of contamination and exposure, the routine use of shoe covers in a H-3 facility is usually weighed against actual need. Shoe covers can offer both a degree of personal protection and control over the spread of contamination on floors. However, in modern facilities where H-3 is largely controlled by the use of secondary containment, shoe covers may not be required. Such facilities can easily maintain a clean laboratory environment by the use of regular smear surveys and good housekeeping. Using liquid-proof shoe covers until spills are cleaned up should be considered following spills of H-3-contaminated liquids and solids to prevent the spread of local contamination.

Gloves

In most operations, the hands and forearms of workers are vulnerable to contact with H-3 surface contamination. The proper use and selection of gloves are essential. Many factors should be considered in selecting the proper type of glove. These include chemical compatibility, permeation resistance, abrasion resistance, solvent resistance, glove thickness, glove toughness, glove color, shelf life, and unit cost. Gloves are commercially available in butyl rubber, neoprene, polyvinyl chloride (PVC) plastics, latex, etc.

The most common gloves found in H-3 laboratories are the light-weight, disposable short glove (usually PVC or latex) used for handling lightly contaminated equipment. Depending on the level of contamination, such gloves may be changed frequently (every 10 to 20 minutes), a second pair may be worn, or heavier gloves may be used instead. When using gloves for this purpose, the work should be planned so that contaminated gloves do not spread contamination to surfaces that are being kept free of contamination. When working in a glove box using the box gloves, disposable gloves are worn to prevent uptake of HTO contaminating the outside of the box gloves. Again, depending on the level of contamination, more than one additional pair may be required, one of which may be a longer, surgeon's length, glove.

In spite of all the precautions normally taken, workers may occasionally be contaminated with H-3. The skin should be decontaminated as soon as possible after any potential skin exposure to minimize absorption into the body. Effective personal decontamination methods include rinsing the affected part of the body with cool water and soap. If the entire body is affected, the worker should shower with soap and water that is as cool as can be tolerated. Cool water keeps the pores of the skin closed and reduces the transfer of HTO across the skin. The importance of washing the affected skin as soon as possible after contamination cannot be over-emphasized.



Nuclear Explosive Operations

Two national laboratories have been involved in research development and testing of nuclear weapons during the Cold War: Livermore, CA and Los Alamos, NM. Sandia National Laboratories, based in Albuquerque, NM, worked on electronic mechanisms, and designs for nuclear warheads and for coupling the warheads to bombs and missiles. The final assembly process of the nuclear weapons occurred primarily at the Pantex Plant in Amarillo, TX. With the end of the Cold War, the plant now disassembles warheads that have been retired from the nation's arsenal, and is now storing the plutonium components. The uranium components are shipped to Oak Ridge, TN, and H-3 canisters are shipped to Savannah River, SC.

The U.S. has performed weapons tests in atmospheric, underwater, and underground tests, mostly in Nevada. Residual radioactive contamination from the testing remains at most of these test sites. The U.S. halted atmospheric testing in 1963 and has not conducted nuclear explosion tests since September, 1992.

An introduction to the classified material can be found in the following unclassified DOE documents: DOE Order 452.1A, *Nuclear Explosive and Weapon Surety Program*; DOE Order 452.2A, *Safety of Nuclear Explosive Operation*; Implementation Guide for DOE Order 452.2A, *Safety of Nuclear Explosive Operation*.

No self-study material has been developed for the nuclear explosive safety area for two main reasons: 1) the material would be voluminous and, in most cases, classified; 2) subject matter experts from around the complex felt that a study guide would be both inappropriate and insufficient to meet the needs of personnel in this area. In an effort to assist personnel to become familiar with this topic, the following are good primer level texts:

- *An Introduction to Nuclear Weapons*, Samuel Glasstone and Leslie M. Redman, U.S. Atomic Energy Commission, WASH-1037, Secret Security Classification required
- *Nuclear Explosive Training Manual*, DOE Albuquerque Operations Office, Secret Security Classification required, (NESD, 505/845-5902)
- *Caging the Dragon - The Containment of Underground Nuclear Explosions*, James Carothers, Lawrence Livermore National Laboratory, DOE/Defense Programs, Defense Nuclear Agency DOE/NV-388, DNA-TR-95-74, unclassified, (423/576-8401).

The Nevada Operations Office developed a "Nuclear Explosive Safety Topical Area Training-to-Competency Curriculum Matrix and Training-to-Competency Matrix" in support of the DOE Technical Qualification Program. It can be found at the following website <http://cted.inel.gov/cted/matrix.html>.



Production/Experimental Reactors

Function

Nuclear reactors are used as a power source to heat water into high pressure steam and produce electricity. The fuel is comprised of U-238 and U-235. One of the by-products in a nuclear reactor is plutonium. Reactors specifically designed to produce Pu-239 are called production reactors. Plutonium is produced from U-238 by capturing a neutron, thus creating U-239 which undergoes beta decay to Np-239, which then decays by beta emission to Pu-239.

Production/experimental reactors are found throughout the DOE complex. One example is the High Flux Isotope Reactor Facility (HFIR) at Oak Ridge National Laboratory. The HFIR is one of the world's most power research reactors. It is a 85-MW isotope production and test reactor with the capability and facilities for performing a wide variety of irradiation experiments. One of the primary purposes of the HFIR is the production of californium-252 and other transuranium isotopes for research, industrial and medical purposes.

Work Activities

Work activities include both normal operations and maintenance. Normal operations usually do not result in significant exposure to plant operators because of the shielding design of the reactor. However, during maintenance, the reactor is shut down and plant systems such as piping, valves, and pumps are opened. Reactor internals contain contamination and higher radiation levels, thus exposing workers. Most of the exposure at reactors occurs during the maintenance phase.

Radiological Hazards

In selecting materials for reactor components, many problems can arise. Core components must meet stringent requirements, such as a low neutron cross section and good high-temperature properties. They should also transfer heat quickly and easily so that materials do not expand or buckle out of shape. The material should resist corrosive agents and radiation damage.

In a nuclear reactor, radioactivity arises, from two nuclear processes: activation of corrosion products and fission. Activation results from the absorption of neutrons by nuclei as they pass through the reactor core in the coolant water. The nuclei result from impurities that enter the coolant water from internal metal surfaces such as stainless steel. Corrosion attacks the stainless steel surfaces releasing microscopic particles of iron, cobalt, nickel and manganese. Some of the more common corrosion products are Co-58, Co-60, Mn-54, Fe-55, Fe-59, and chromium-51 (Cr-51).



Major Activated Corrosion Products

Nuclide	Half-life	Formation Reaction	Major Source(s)
Cr-51	27.70 days (d)	Cr-50 (n, γ) Cr-51	steel
Mn -54	312.2 d	Fe-54 (n,p) Mn-54	steel
Mn-56	2.579 hours (h)	Mn-55 (n, γ) Mn-56	steel
Fe-59	44.51 d	Fe-52 (n, γ) Fe-59	steel
Co-58	70.9 d	Ni-58 (n,p) Co-58	steel and nickel
Co-60	5.272 years (y)	Co-59 (n, γ) Co-60	stellite and steel

The most predominant corrosion product is Co-60, which originates from valve seats or surfaces. As valves are opened and closed, the valve plunger wears against the valve seat releasing microscopic particles into the coolant water which become activated when passing through the core by absorbing a neutron.

Fission Products

Radionuclide	Decay Mode	Decay Energy (MeV)	Half-life	Biological Hazard
Kr-85	beta, gamma	β , 0.687	10.7 years (y)	skin, external
Kr-85m	beta, gamma	β , 0.820	4.5 hours (h)	skin, external
Kr-87	beta, gamma	β , 3.80	76.3 minutes (m)	skin, external
Kr-88	beta, gamma	β , 2.80	2.84 h	skin, external
Xe-133	beta, gamma	β , 0.346	5.27 days (d)	skin, external
Xe-133m	gamma	γ , 0.233	2.26 d	skin, external
I-131	beta, gamma	β , 0.806	8.05 d	thyroid
I-133	beta, gamma	β , 1.27	20.8 h	thyroid
Cs-137	beta, gamma	γ , 0.662	30 y	whole body, external
Sr-90	beta	β , 0.546	27.7 y	bone surface



Control Techniques

ALARA at reactor facilities include design features and administrative controls. ALARA is designed into the reactor facilities by using a "defense in depth" approach. A defense in depth uses multiple barriers to prevent radioactive material from entering the environment. The barriers may include control rods, a water or heat transfer medium, piping system, reactor vessel, reactor vessel containment, and reactor building. Effluents can be held up for decay, stored, and/or filtered to permissible levels before release or disposal.

ALARA will be maintained by a comprehensive RPP outlined by management. Administrative controls may include ALARA policy requirements such as administrative control levels lower than the federal limits, procedures, and worker training. Worker training should emphasize time, distance, and shielding. Physical controls may include shielding, radiological postings, personnel monitoring, locked and/or fail safe doors and remote handling devices. Frequent audits of the RPP should be conducted to verify ALARA is being maintained.

Accelerator Operations

Function

Accelerators are used to accelerate charged particles to very high energies and then to bombard a target. Formally, an accelerator is any machine used to impart large kinetic energies of charged particles such as electrons, protons, and atomic nuclei; and, are capable of creating a radiological area. These accelerated particles are then used to probe nuclear or subnuclear phenomena. There are also many accelerators in industrial and medical applications. Accelerators consist of the following major components: a high voltage supply, ion source, beam pipe, magnet, targets, beam dump, vacuum system, and shielding. For detailed information on accelerator physics, consult the following web page:

<http://www-laacg.atdiv.lanl.gov/accphys.html>

Work Activities

Particle accelerators are designed for a variety of purposes, such as research into the nature of matter, production of radioisotopes, generation of bremsstrahlung for radiography, induction of fusion, pumping of lasers, and production of synchrotron radiation. Each purpose dictates a particular energy range and choice of particle to be accelerated; electrons, protons, or nuclei of heavier elements. For a particular primary beam, the health physicist has to understand the radiation fields produced as the beam is absorbed, since the resultant dose rates can be quite high.



Types of accelerators employed at DOE include:

1. Van de Graaff Generator, a polished metal sphere and movable belt which carries electrical charges up to the sphere where stored. Once the sphere is charged to its maximum voltage, the particles are ejected into the accelerating tube. The Van de Graaff generator primarily serves two purposes; 1) as a source of particles for research in low-energy nuclear physics, and 2) to inject particles into larger accelerators.
2. Linear Accelerators, are a series of alternating electrodes which are connected electrically to each other, and holes bored through them permit the passage of the beam. The electric field created by the electrodes accelerates the charged particles. There are two main types of linear accelerators; 1) the drift tube, and 2) the wave guide.
3. Cyclotron, is a cyclic accelerator in which the charged particles spiral outward from the center of the machine as they gain energy.
4. Synchrotrons, are accelerators in which the energy of the charged particle is increased as it travels around a circular orbit of fixed radius.
5. Colliders, are accelerators in which two opposed beams of particles collide head-on.

Radiological Hazards

Particle accelerators pose unique problems for health physics. The radiation given off at accelerators can be loosely classified as prompt and induced. This includes both direct exposure to radiation fields and airborne radionuclides.

Prompt radiations are produced while the accelerator is operating and include primary and secondary radiations. Primary radiation, produced by the primary particle beam, can produce enormous dose rates of radiation over small areas at the target. The secondary radiation (bremsstrahlung, neutrons, protons, gamma rays and scattered electrons) can create very high dose rates over large areas of the accelerator workplace. Some secondary radiation is quite penetrating. Bremsstrahlung is produced in the target and in air along the beam path. Neutrons are generated by a number of means such as (α, n), (p, n), and (γ, n).

If the energy of the primary beam is high enough, induced radioactivity can be produced by neutron activation of air, collimators, target and beam stop materials and cooling water. Activation products can continue to produce radiation after the accelerator is shut down.

Airborne-radioactivity can result from both neutron activation and photo-neutron reactions with air principally oxygen and nitrogen. The most predominant airborne products nitrogen-12 (N-12), oxygen-15 (O-15), and carbon-11 (C-11), are positron emitters with half lives of less than 20 minutes. The decay of all positron emitters is accompanied by two 511 KeV gamma rays which are produced when the positron is ultimately annihilated.



Radionuclide	Common Source	Decay Mode	Decay Energy (MeV)	Half-life	Biological Hazard
N-13	air	positron	β^+ , 1.20	10 minutes (m)	external
O-15	air, water	positron	β^+ , 1.74	2 m	external
C-11	air, water	positron	β^+ , 0.970	20.4 m	external
H-3	cooling water	beta	β , 0.0186	12.3 years (y)	internal
Be-7	plastics, oil	gamma	γ , 0.477	53.6 days (d)	external
Na-22	concrete	positron	β^+ , 1.82	2.6 y	external
Ni-57	steel	positron	β^+ , 0.850	36 hours (h)	external
Cu-64	copper	positron, beta	β^+ , 0.65, β , 0.570	12.8 h	external
Mn-54	steel	gamma	γ , 0.835	303 d	external
Zn-65	copper	positron	β^+ , 0.327	245 d	external

Control Techniques

Since accelerators have the potential to generate very high dose rates, they have shielding designed to reduce radiation levels to acceptable values. Historically, a common weak point in accelerator design has been thin-roof shielding. As a result "skyshine" from airscattered neutrons contribute significantly to the radiation dose in uncontrolled areas. Other design features are interlocks that prevent entry into areas where the beam is in operation or shut the beam off if an entry door is opened. Interlock systems should be periodically checked to ensure proper operation.

Materials selection is very important to minimize activation of accelerator and beam-dump materials. Routine discharges and spills of radioactive water could also be a problem. Common sources of radioactive water are the closed loops containing water to cool magnets, targets and beam dumps. For a listing of good references on accelerator and beam physics, see web page:

<http://www.slac.stanford.edu/grp/arb/dhw/dpb/w3v1/books.html>

Another helpful source of information is DOE-HDBK-1108-97, *Radiological Training for Accelerator Facilities*, and can be found on the following web page:

<http://tis-nt.eh.doe.gov/WPPHM/RST/rst.htm>



Radiation Protection Competency 1.9

The student manual to this course provides detailed information on facility description, radiological concerns, types of controls, monitoring, radioactive waste issues, and abnormal conditions (i.e., loss of beam containment, radiation overexposure, etc.).

Decontamination and Decommissioning (D&D)

The following sections are from the "Introduction" sections of the *Decommissioning Resource Manual* and the *Decommissioning Handbook*. To obtain copies of these documents, contact:

Remedial Action Program Information Center (RAPIC)
138 Mitchell Road
Oak Ridge, TN 37830-7918
phone: 423/576-6500
FAX: 423/576-6547
E-mail: rapic@ornl.gov

DOE/EM-0246, *DECOMMISSIONING RESOURCE MANUAL*

Introduction: Purpose and Scope of this Resource Manual

The purpose of this Resource Manual is to provide a reference resource for the Department of Energy (DOE) decommissioning program conducted by the Office of Environmental Restoration (EM-40). The manual provides information to assist in the effective implementation of the Decommissioning Framework specified in the *Environmental Restoration Program Decommissioning Implementation Guide*, May 22, 1995 (included as Appendix A of this manual). The *Implementation Guide* and the Framework it describes are consistent with the *Policy on Decommissioning of Department of Energy Facilities Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)*, May 22, 1995 (included as Appendix B of this manual). This manual provides background on the development of decommissioning policy and the framework, identifies decommissioning steps, suggests contents of documents, provides suggested decommissioning practices, describes the respective roles of DOE Headquarters and field organizations, and provides additional information on a variety of decommissioning functional topics.

The provisions of this manual are intended to replace the programmatic (nontechnical) suggestions found in Chapters 2 through 5 of the *Decommissioning Handbook* (document number DOE/EM-0142; March, 1994).

A revision of the Resource Manual is planned for the near future after field decommissioning planners and managers have had an opportunity to work with the document and to provide comments.



DOE/EM-0142P, *DECOMMISSIONING HANDBOOK*

Introduction: Handbook Purpose

The *Decommissioning Handbook* has been prepared under contract to the U.S. Department of Energy (DOE) to provide technical guidance on the decommissioning—commonly known as *decontamination and decommissioning (D&D)* of commercial and governmental nuclear facilities. Because of the unique hazards incumbent in nuclear facilities, their design, licensing, and startup (commissioning) require a stepwise program to address safety. Similarly, because of residual radioactivity, the termination of operations (decommissioning) presents unique hazards that must be addressed from a programmatic, safety, environmental, and technological standpoint. This handbook provides technical guidance for decommissioning activities, including characterization, decontamination, dismantling, and disposition (disposal or salvage) of a facility's equipment and structures. Waste treatment is also considered a decommissioning activity, depending on the regulatory requirements for material disposal and/or the wastes generated by decontamination. In addition to technical guidance, this document provides an overview of the decommissioning process, including planning, applicable regulations, and supporting activities (e.g., transportation and worker and environmental protection). This overview explains the background and organization of this document, briefly mentions the technical subjects addressed, and reviews the peripheral (nontechnical) considerations that must be addressed during a decommissioning project.

This handbook is primarily a technology identification document; thus, the chapters identifying technologies are the focus of the handbook. To encompass the entire decommissioning project—including detailed planning requirements, funding, estimating, and decommissioning operations—is far beyond the scope of this handbook. The reader is referred to other documents for details involving these important elements of a total decommissioning project. Some of these documents are the DOE orders concerning D&D and cost estimation, the proposed guidance document under preparation for DOE headquarters, applicable NRC regulations, and the pending codification of DOE orders regarding decommissioning in Title 10 of the Code of Federal Regulations (10 CFR).

The Remedial Action Program Information Center (RAPIC) provided research information on D&D to support the development of this handbook. RAPIC, a support group to the DOE Office of Environmental Restoration (ER) (EM-40), provides technical information support to all DOE ER programs, program participants, and the scientific community involved in environmental restoration activities. The use of RAPIC or other databases is recommended to obtain the most current information available for a specific technology described in this handbook or identified as part of an individual decommissioning project.

The *Decommissioning Handbook* was prepared concurrently with a guidance document that provides specific programmatic guidance for planning decommissioning for DOE-owned facilities. The programmatic guidance outlines the full DOE planning process for decommissioning. The technologies and methods outlined in this handbook can be used in concert with the guidance document to arrive at a comprehensive plan for a decommissioning project. The handbook was prepared as a tool to allow the reader to efficiently research decommissioning technologies by providing a single convenient resource.



Function

At the end of their useful life, nuclear reactors and facilities must be shut down and decommissioned. To date, only a few nuclear reactors have been fully decommissioned; several more are in the planning. The major volumes of radioactive waste will result from the decommissioning of DOE facilities.

Decommissioning activities are carried out under the authority of the Atomic Energy Act (AEA) and according to requirements set forth in various DOE Orders and standards and other guidance documents.

Work Activities

The D&D activities at such installations may result in very large volumes of low-level waste, depending on the methods selected. The three major classifications for decommissioning nuclear facilities are decontamination, safe storage, and entombment. Most DOE facilities will be demolished following decontamination.

The **decontamination** alternative is one in which the equipment, structures, and portions of a facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use.

The **safe storage** is a method in which the nuclear facility is shut down and maintained in a safe, non-operational status until it can subsequently be decontaminated (deferred decontamination) to levels that permit release for unrestricted use.

The **entombment** alternative is one in which radioactive contaminants are encased in a structurally long-lived material, such as concrete. The entombment structure is appropriately maintained and continued surveillance is carried out until the radioactivity decays to a level permitting the unrestricted release of property. For short-lived radionuclides this time period could be on the order of 100 years. If the contaminants cannot be removed or released for unrestricted use, they will simply remain DOE restricted property (e.g. the Hanford, WA area).

Radiological Hazards

The radiological hazard present depends on the decommissioning alternative chosen, type of facility being decommissioned, and the types of waste generated. Radioactive wastes from decommissioning can be grouped into three major categories:

1. Neutron activated
2. Contaminated
3. Miscellaneous



Radiation Protection Competency 1.9

Neutron activated waste materials include the reactor vessel and its internal components. High-activity activation wastes from the decommissioning of reactor internals are estimated to make up less than 1% of the total radioactive waste volume, but contain more than 95% of the activity. Most of the radioactivity is in a single reactor component, the stainless steel core shroud that surrounds the reactor fuel, from long-term irradiation of stainless steel and other alloys of which Co-60 comprises the most activity.

Neutron Activated Wastes

Radionuclide	Decay Mode	Decay Energy (MeV)	Half-Life	Biological Hazard
Co-60	gamma	1.17 & 1.33	5.27 years	external
Ni-59	electron capture	x-rays	76,000 years	internal
Ni-63	beta	0.0669	100 years	internal
Nb-94	beta, gamma	0.473, 0.871	20,000 years	external

Contaminated materials include much of the piping and equipment in the reactor containment, fuel handling, and auxiliary control buildings. In addition, some concrete surfaces of these buildings are expected to be radioactive and will require removal.

Control Techniques

Control techniques may include extensive decontamination before handling the wastes. Decay is another option for the shorter lived Co-60 which causes the most exposure. The standard ALARA techniques of time, distance, and shielding would also apply.

Radiation-Generating Devices (RGDs)

RGDs are not precisely defined in the *Radiological Control Manual*; however, Implementation Guide (IG), G-10 CFR 835/C3 (Revision 1), *Radiation-Generating Devices*, defines RGDs as "a collective term for devices which produce ionizing radiation, sealed sources which emit ionizing radiation, small particle accelerators used for single purpose application that produce ionizing radiation (e.g., radiography), and electron-generating devices that produce x-rays incidentally."



Function

RGDs are used at DOE sites for a variety of reasons, including:

- analytical x-ray devices, or electron beam machines.
- small accelerators used for radiography or other single purpose applications.
- radiation or electron generating devices that produce x-rays incidentally.
- sealed gamma-ray sources.
- sealed neutron sources.
- particle accelerators.
- neutron generators.
- electromagnetic pulse generators (capable of producing ionizing radiation).
- electron microscopes.
- electron arc welders.
- microwave cavities that produce x-rays incidentally.
- cabinet x-ray machines used for security applications.

All the RGDs addressed in the IG may be classified as either devices that must be electrically energized to produce ionizing radiation or sealed sources consisting of encapsulated isotopes that emit radiation continuously. They are used at DOE sites with a great variety of configurations and operating characteristics and in a wide spectrum of applications. This IG addresses RGDs used for industrial and research applications.

To ensure individual safety from radiation, RGDs used at DOE sites should be operated within an exempt shielded enclosure or installation. These installations protect individuals by providing physical shielding and/or controlling access to areas where RGDs are operated. All new RGD installation designs and the modification of old RGD installations "shall" consider radiation protection in their design objectives (10 CFR 835.1002 and *Radiological Control Manual* 128). Further detailed guidance is provided in the IG.

X-ray fluorescence is a useful technique for determining the concentration of a variety of elements in a wide range of sample types. The technique is based on the fact that: 1) no two elements possess identical electron orbital energies, and 2) each element emits x-rays of unique energy when irradiated with x-rays of sufficient energy to eject inner shell orbital electrons. X-rays of unique energy emitted by a specific element are called characteristic x-rays of the element. The energy of the characteristic x-rays emitted by an irradiated sample can be identified with a detector, and are the basis for the qualitative and quantitative analysis of unknown substances by x-ray fluorescence.



Radiological Hazards

RGDs have the potential to generate very high external dose rates and, therefore, pose a significant external radiation exposure hazard if proper controls are not used. DOE invokes the American National Standards Institute (ANSI) standards for the use and handling of RGDs. Also, the Implementation Guidance for use with Title 10, Code of Federal Regulations, Part 835 on RGDs, G-10 CFR 835/G (Revision 1), *Radiation-Generating Devices*, can be found on the following web site:

<http://tis-nt.eh.doe.gov/whs/whs.html-ssi>

Control Techniques

Special considerations associated with the use of RGDs include the presence of extremely high dose rates and the potential for uncontrolled exposures. Operation of these devices requires stringent physical and administrative controls to prevent overexposure to operating and support personnel and those in adjacent work areas. Radiographers should have training in accordance with 10 CFR 34.31. RGDs operators should have training appropriate for the radiation source involved and commensurate with the level described in 10 CFR 34.31.

ANSI N 43.2-1988, *Radiation Safety for x-Ray Diffraction and Fluorescence Analysis Equipment*, recognizes two classes of x-ray systems, enclosed-beam systems and open-beam systems. Both types are required to have a beam trap, visible signal of x-ray production at the exposure switch as well as at the source housing, and a fail-safe interlock for x-ray tube disassembly. Operating procedures and beam alignment procedures shall be documented by the manufacturer and followed by the users. Alignment procedures should be designed so that radiation exposure to the hands and eyes are minimized. Open-beam units are typically more hazardous than the enclosed beam systems. The open-beam systems are required to have shutters with fail-safe design, and shutters on all ports interlocked with the collimator coupling. A guard or interlock should be used to prevent entry of body parts to the primary beam. The enclosed systems are required to have a chamber interlocked with the high voltage generator so that no x-rays are produced when the chamber is open.

Most injuries occur during nonroutine repair and alignment. The users should operate the equipment according to the manufacturer's specifications, and follow the manufacturer's recommended alignment procedures. If modifications are necessary, the radiation protection organization must approve the changes. Also, nonstandard accessories should not be aligned until procedures have been approved. All users and maintenance personnel should be cautioned to not remove covers, shielding materials, or tube housings; or make modifications to shutters, collimators, or beam stops until the beam is off.

10 CFR 34, *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations*, applies only to sealed gamma ray sources used in radiography by the Nuclear Regulatory Commission (NRC) or NRC Agreement State licensees. It is not a mandatory standard for adoption by DOE facilities. Some of the requirements in this NRC regulation are for exposure devices, such as



coupling the source to the drive cable, labeling the source capsule and exposure device, locking the exposure device when not in use, and physically securing the exposure device during transport or storage. Other requirements include leak-testing the source every six months, performing radiation surveys at various stages of radiography, calibrating survey instruments every three months, performing a quarterly inventory of sources, and adhering to requirements for operating and emergency procedures. In 10 CFR 34, three types of personnel monitoring are required: a whole-body film badge or thermoluminescent dosimeter (TLD), a pocket ionization chamber, and an alarming ratemeter. The most frequent cause of accidental exposures (at least among NRC or Agreement State licensees) is a failure of the radiographer to perform surveys, which has resulted in exposures from sources that were left in the unshielded position. It includes:

10 CFR 34.31, Training, is the section that addresses the training of radiographers. It is fairly specific in content and time requirements.

I. Fundamentals of Radiation Safety

- a. Characteristics of gamma radiation
- b. Units of radiation dose (mrem) and quantity of radioactivity (curie)
- c. Hazards of exposure to radiation
- d. Levels of radiation from licensed material
- e. Methods of controlling radiation dose
 - time
 - distance
 - shielding

II. Radiation Detection Instrumentation

- a. Use of radiation survey instruments
 - operation
 - calibration
 - limitations
- b. Survey techniques
- c. Use of personnel monitoring equipment
 - Film badges
 - TLDs
 - Pocket dosimeters
 - Alarm ratemeters



- III. Radiographic Equipment to be Used
 - a. Remote handling equipment
 - b. Radiographic exposure devices
 - c. Storage containers
- IV. Inspection and Maintenance Performed by the Radiographers
- V. Case Histories of Radiography Accidents

Environmental Restoration

Function

The fundamental goal of the DOE Office of Environmental Restoration (DOE/EM-40) is to ensure that the risks to the environment and human health and safety, posed by inactive and surplus facilities and sites, are either eliminated or reduced to prescribed safe levels. Environmental restoration efforts are proceeding in two major areas: remedial action (RA) and decommissioning. The principle regulatory requirements for RAs are derived from the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Activities may be subject to further requirements associated with compliance with the National Environmental Policy Act (NEPA) and with regulatory requirements imposed by the states.

The environmental problems DOE faces today are the result of years of research, development, and production, with little attention given to the management of waste and by-product disposal. Wartime urgencies and other national priorities took precedence over cleanup efforts. As was characteristic of the time, DOE lacked knowledge of the full impact of environmental contamination. The waste management practices considered adequate at the time do not have an infinite life.

In the late 1980s, the priorities of DOE and the nation turned toward environmental protection. DOE began an all-encompassing shift in mission from a national defense priority to a mission of environmental consciousness, accountability, compliance, and cleanup.

EM's objectives include containment of contamination at inactive sites; treatment, storage, and disposal of the current inventory of hazardous, radioactive, and mixed waste in a safe, environmentally sound, and cost-effective manner; and bringing all DOE facilities and sites into compliance with applicable laws and regulations.

The DOE has 10 field offices which manage the cleanup and containment of hazardous and radioactive wastes at numerous DOE sites (see attachment). Two additional programs, the Formerly Utilized Sites Remediation Act Program (FUSRAP) and the Uranium Mill Tailings Remedial Action Program (UMTRAP) are also under EM, and deal specifically with the cleanup of sites contaminated during the Manhattan Project.

Work Activities



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A number of DOE facilities are on the EPA National Priorities List. Work activities under RAs include site discovery, preliminary assessment, and inspection; site characterization, analysis of cleanup alternatives, and selection of remedy; cleanup; site closure; and site compliance monitoring.

Radiological Hazards

Three major radioactive waste classes associated with environmental restoration activities are: low-level waste (LLW), transuranic waste (TRU), and by product material. Environmental restoration activities are not expected to generate or handle high level waste (HLW) or spent nuclear fuel (SNF). In addition to radioactive waste contaminants, these wastes can also be contaminated with hazardous constituents as regulated by RCRA and TSCA. Such wastes are defined as mixed wastes. Thus a total of six waste classes are relevant for radioactively contaminated material resulting from environmental restoration activities: LLW, mixed LLW, mixed TRU.

The radioactive contaminants in environmental restoration wastes could be a wide variety of radionuclides, depending on the operations performed at the site. A list of radioactive contaminants can be obtained from the site characterization data.

Environmental restoration wastes are different from those associated with processing operations, in that the former generally have much lower concentrations of radioactive and chemically hazardous substances. Much of the material requiring remediation is a consequence of past activities (e.g., spills, waste disposal, and environmental releases such as liquid discharges to drainage basins). The types of contaminated wastes include a great deal of soils, including sediment and sludges. In addition, environmental restoration wastes may include debris such as concrete, metal, brick, wood, asphalt, plastic and rubble.

Environmental restoration wastes also differ from those resulting from processing operations, in that the former are generally highly heterogeneous in physical form and chemical constituency. In addition a full spectrum of contaminants could be associated with these previously disposed materials, including those associated with ordnance operations, processing of uranium and thorium ores and concentrates, and the operation of nuclear reactors and associated chemical processing plants.



Control Techniques

Due to the low-activity levels in most of the environmental restoration wastes, exposure of occupational personnel is not the main concern. Public exposures via groundwater contamination may require interim actions to mitigate doses. Interim actions are used to address urgent risks and remove potential threats before the completion of detailed characterization studies. In 1994, the EM-40 program completed 119 of these actions. In 1995, DOE completed another 100 interim actions, bringing the total to more than 500 since the program was initiated.

A QUICK TOUR OF THE DOE'S NATIONAL PRIORITIES LIST (NPL) SITES THE NATIONAL PRIORITIES LIST

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandated that the EPA compile the National Priorities List (NPL), which is a formal listing of the Nation's worst hazardous waste sites (including Federal sites). Specifically, the NPL is a list of sites in the United States where uncontrolled hazardous substance releases have occurred that are priorities for long-term remedial evaluation and response. The EPA updates the NPL twice a year.

A site may be deleted from the NPL when the EPA has determined that no further cleanup response is deemed appropriate (i.e., the release poses no significant threat to public health or the environment). However, releases cannot be deleted from the NPL until the State in which the release is located has concurred on the proposed deletion. To ensure public involvement during a proposal to add or delete a release from the NPL, a notice is published in the Federal Register and public comments are solicited during a public comment period.

There are 18 DOE listings representing 15 discrete locations (the Hanford site is listed three times---one each for the 100Area, 200Area, and 300Area, and the Main Site and Site 300 of the Lawrence Livermore National Laboratory [LLNL] are listed separately).

(1) Oak Ridge Reservation, Oak Ridge, Tennessee

The Oak Ridge Reservation was established as the Clinton Engineer Works, the first of the Manhattan Project sites, in September 1942. It is one of the DOE's largest and most diversified sites, with programs supporting the entire spectrum of the Department's missions. The Oak Ridge Reservation consists of three separate sites: a national laboratory, a manufacturing and development engineering plant, and a national demonstration site for innovative environmental restoration and waste management technologies. As a result of the plants' historical missions, several offsite areas were contaminated. Environmental restoration (ER) activities for these areas are also handled by the Oak Ridge Environmental Management program.

The Oak Ridge National Laboratory (ORNL) covers 2,900 acres 10 miles southwest of the center of the city of Oak Ridge. The Laboratory's mission is to conduct applied research and development in energy technologies and to perform basic research in selected areas of the physical and life sciences. Past research, development, and waste management activities at the Laboratory have produced a number of areas contaminated with low-level and/or hazardous chemical waste that require remediation. Currently, the Laboratory generates waste contaminated with several radioactive elements. This waste is treated, stored, and disposed of through the Waste Management program.

The main sources of the ORNL's waste have been radioisotope production, experimental reactors, research labs, and analytical laboratories. Solid wastes from other sites contributed a large fraction of the volume and radioactivity buried in the Solid Waste



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Storage Areas (SWSAs) between 1955 and 1963. During this time, the Reservation served as the AEC's regional disposal facility for the southern region. A number of ORNL sites are known or are suspected to contain buried TRU wastes; however, waste inventories appear to be dominated by H-3 and fission and activation products.

Remedial actions at the ORNL proceed under a Federal Facility Agreement for the Oak Ridge Reservation with the DOE, State of Tennessee, and EPA, Region IV. A large number of facilities at the ORNL have been declared surplus because the programs for which they were built have been completed. Because the potential exists for release of radioactivity to the environment from these facilities, they will be decontaminated and decommissioned in the future. A structured program of surveillance and maintenance is ongoing with these facilities until decontamination and decommissioning (D&D) can begin.

The K-25 Site

The 1,500-acre K-25 Plant, formerly the Oak Ridge Gaseous Diffusion Plant, was constructed as part of the Manhattan Project between 1943 and 1945, with major additions and upgrades during the 1950s and 1970s. Its original mission was to produce enriched uranium hexafluoride for use in atomic weapons and, later, for power reactors.

A declining demand for enriched uranium resulted in shutdown of the enrichment process at the K-25 Plant in 1987. Currently, the K-25 site has a multipurpose mission while awaiting D&D of the gaseous diffusion plants so that the facilities may be used for other purposes. The K-25 site now serves as the location for many contractor central staff functions, environmental restoration and waste management organizations, and for operating waste treatment and storage facilities. The K-25 site hosts the Toxic Substances Control Act (TSCA) Incinerator, a facility for the destruction of mixed waste. Construction of the incinerator was completed in 1988. The TSCA Incinerator can destroy more than 2 million pounds of hazardous/mixed waste each year.

Operation of the K-25 Plant has resulted in sites that contain hazardous materials and wastes. These sites include burial grounds, storage facilities, underground storage tanks, surface impoundments, treatment facilities, process equipment, accumulation areas, and other areas having the potential for releasing hazardous constituents to the environment. Approximately 140 waste management units have been identified at the K-25 site. A multiple facility activity is underway to address migration of radionuclides, metals, and organic compounds beyond the boundary of the DOE Oak Ridge Reservation that have contaminated off-site public surface waters.

Removal of hazardous materials and equipment, such as asbestos from seam lines, will continue through 1998 in the K-25 D&D Program, which will affect more than 80 buildings. The Program's primary focus during this period will be to conduct remedial investigations of 16 operable units and perform preliminary assessments of 12 other sites.

The Y-12 Plant

The 811-acre Y-12 Plant was built in 1943 as part of Manhattan Project to separate uranium isotopes by electromagnetic processes. When the separation process was discontinued after World War II (in favor of the more efficient gaseous diffusion method of uranium enrichment), Y-12's role changed to manufacturing and developmental engineering. Recently, Plant production has been decreased due to a diminished need for weapons components. Currently, the Plant has four principal missions: (1) Producing nuclear weapon components and subassemblies and supporting the DOE's weapons design laboratories, including development and fabrication of test hardware; (2) Processing source and special nuclear materials; (3) Supporting other DOE installations at Oak Ridge as well as at Paducah, Kentucky; (4) Providing support to other Government agencies.

The combination of production, developmental engineering, and support activities at the Y-12 Plant represents an integrated capability not normally available in production complexes. From a high-technology base of operations, the Plant can handle all aspects of manufacturing, including chemical processes, fabrication systems, instrumentation, nuclear materials processing, and waste management.

Site contamination at the Y-12 Plant has been found to include hazardous materials, low-level radioactive material (mostly



uranium), and mixed wastes resulting primarily from the weapons components production process. Contaminated sites in need of restoration include old waste disposal sites, waste storage tanks, spill sites, and contaminated inactive facilities. In addition, significant inventories of mercury are present on-site and off-site in the East Fork Poplar Creek floodplain soils and sediments. Potential health risks exist from off-site migration of contamination, principally mercury. Many ER Projects at Y-12 have moved beyond the assessment stage and are actively being cleaned up.

There is currently a proposal to consolidate the nonnuclear component of the nuclear weapons complex manufacturing activities. In accordance with this proposal, transition activities at the Y-12 Plant are in the planning stage, but no final decisions have been made regarding these activities.

The Oak Ridge Reservation was placed on the NPL in November 1989. Contaminated sites are being assessed and remediated in accordance with the Federal Facility Agreement for the Oak Ridge Reservation with the State of Tennessee and Region IV of the EPA.

(2) Hanford, Richland, Washington (3 Listings)

The Hanford site was the second of the Manhattan Project sites, established in January of 1943. It is located near Richland Washington and occupies 560 square miles within the Columbia River Basin in the southeastern part of the State. The Hanford site's activities have included plutonium production and separation, advanced reactor design and testing, basic scientific research, and renewable energy technologies development. Now, activities are primarily focused on environmental restoration and waste management.

Nuclear and chemical wastes (including hazardous, low-level and high-level radioactive, transuranic, and mixed wastes) have been accumulating at the site since 1943. Much of this waste was disposed of underground. In some cases, wastes have been released or have leaked into the ground or ground water. There are nine surplus production reactors on the site, all of which are shutdown.

Over 1,100 waste sites have been identified at the Hanford site that require characterization and may require subsequent remediation. Most of these cleanup sites originated from on-site storage or disposal of low-level waste (LLW), mixed LLW, and hazardous waste, typically generated from plutonium production and separation. The waste sites range in size from one square foot to several hundred acres, and they are grouped into 78 operable units. The Hanford site was listed on the NPL in 1989 three times one for the 100Area, 200Area, and 300Area.

Hanford's former production mission has changed to environmental restoration and waste management. A Tri-Party Agreement signed by the DOE, the EPA, and the State of Washington in 1989 and amended in 1991, 1994, 1995, and 1996, established enforceable milestones for the inactive waste sites by the year 2018. In addition, more than 100 surplus facilities at the Hanford site are contaminated with radioactivity and must undergo D&D. These activities will include the surplus reactors, chemical processing buildings, and other structures such as exhaust stacks, storage tanks, and river outfall structures.

(3) Mound Plant, Miamisburg, Ohio

Most of the Mound facility is located within the southern city limits of Miamisburg in southwestern Ohio. The Mound Plant covers 756 acres in an area overlooking Miamisburg and the Great Miami River. Dayton is about 10 miles north-northeast of the installation.

The Mound Plant was established in 1948 to manufacture nonnuclear and H-3-containing components for nuclear weapons. Mound is an integrated research, development, and production facility performing work in support of DOE weapons and energy programs, with an emphasis on explosives and nuclear technology. Other activities at the Mound Plant include the following:



separation, purification, and sale of stable isotopes of noble gases; solar energy research; fossil fuels research; nuclear safeguards; waste management; plutonium heat source testing; fusion fuel systems.

Operations at the Mound Plant have historically generated both airborne and liquid waste streams containing H-3. Elevated levels of H-3 detected in the ground water at the Mound Plant are probably related to earlier liquid releases. Trace levels of chlorinated organics have been attributed to solvents that were either used in high-explosives processing or were incidental to industrial operations. The processing, handling, and storage of plutonium resulted in the contamination of several laboratories, building support areas, and several on-site and off-site locations. Storage, handling, and repackaging of thorium sludge resulted in the contamination of on-site soils with thorium. The Mound Plant was placed on the NPL in November 1989.

The ER Program at the Mound Plant is an ongoing effort to characterize, assess, and cleanup the sites that have been contaminated due to past operations.

(4) Monticello (Uranium) Mill Tailings Site, Monticello, Utah

The Monticello Mill Tailings site was placed on the NPL in November 1989. The Monticello Mill is a 110-acre uranium and vanadium processing site that was acquired by the Atomic Energy Commission (AEC) in 1948. The mill remained active through 1960. Prior to closing the mill site in 1961, contaminated tailings from the site had been used throughout the town of Monticello for various construction projects. Tailings were also spread to surrounding areas by water erosion and wind dispersal.

The milling site includes the volume of tailings (on 10 acres), contaminated soil, and contaminated building material in the tailings impoundments and mill area, estimated at 2.2 million cubic yards.

The DOE signed a Federal Facility Agreement in 1988 with the EPA and the State of Utah to remediate these contaminated sites. A CERCLA Record of Decision (ROD) was issued in September 1990 for the mill site. An on-site disposal cell has been constructed; hauling of tailings to the cell will begin in FY 1997, and placement of all contaminated material in the cell will be completed in FY 1999.

(5) Idaho National Engineering Laboratory, Idaho Falls, Idaho

The Idaho National Engineering and Environmental Laboratory (INEEL) covers 890 square miles of the eastern Snake River Plain and is located approximately 21 miles west of Idaho Falls, Idaho. About 270 square miles of this area was once used as a gunnery range by the U.S. Navy and U.S. Army Air Corps. The INEEL was established in 1949 by the AEC as an area to build, test, and operate various nuclear reactors and support facilities with maximum safety and isolation. Originally known as the National Reactor Testing Station, it was renamed as the Idaho National Engineering Laboratory (INEL) in 1974 to reflect the broad scope of research and engineering activities conducted at the site, and the INEEL in 1997.

Today, the INEEL is one of the DOE's principal centers for conducting nuclear energy research and development. The INEEL has the world's largest and most varied collection of nuclear reactors, including research, testing, power, and ship propulsion reactors. Its current mission is to develop, demonstrate, and deploy advanced engineering technologies and systems to cultivate U.S. competitiveness and security, improve the efficient use and production of energy, and enhance the quality of life and the environment.

One function of the Laboratory was to recover highly enriched uranium and krypton-85 (Kr-85) from spent nuclear fuel generated by naval reactors. The recovered enriched uranium was used in fuel elements for the Savannah River production reactors. The Kr-85 was shipped to the Oak Ridge National Laboratory (ORNL) for commercial sale (including defense-related electronics industries). The INEEL was the only source of Kr-85 in the Western World, but reprocessing operations and, therefore, Kr-85 recovery were discontinued in April 1992. Emphasis is now focused on spent fuel storage and developing high-level waste (HLW) treatment technologies.



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Historic operation of the INEEL has resulted in chemical and radioactive contamination of the soil and ground water at the site. Approximately 368 individual sites have been identified as potentially being contaminated. The INEEL was placed on the NPL in 1989 primarily because of potential ground water contamination. Environmental restoration activities at the site are proceeding under a Federal Facility Agreement/Consent Order signed in December 1991 between the DOE, EPA (Region X), and State of Idaho. To facilitate environmental restoration activities, the INEEL has been divided into 10 regions known as waste area groups (WAGs).

Because the INEEL historically received transuranic (TRU) waste from the Rocky Flats Plant, and because of past operations, the site manages a very large quantity of TRU waste. Prior to 1970, this waste was buried as low-level waste. Since 1970, this waste has been retrievably stored. The future management of this waste is a major challenge to the EM Program at the site. Restoration activities to cleanup the INEEL consist of remedial investigations and remedial actions and D&D of surplus facilities. Included in INEEL restoration activities is the Inactive Underground Storage Tank Program, which has removed 117 out-of-service or abandoned underground tanks at INEEL sites. This Program has yielded 125 tons of metals and 40,000 gallons of fuel oil, all of which have been recycled.

(6) Savannah River Site, Aiken, South Carolina

The Savannah River Site (SRS) covers 325 square miles along the Savannah River near Aiken, South Carolina and was established in 1950 to produce H-3 and plutonium in the effort to expand the development of thermonuclear weapons. The original construction site encompassed five nuclear reactors, two chemical separation plants, a heavy water extraction plant, a nuclear fuel and target fabrication facility, and a waste management facility.

The SRS's historical mission was to support national defense efforts through the production of nuclear materials, primarily H-3 and plutonium. Its current focus is on Waste Management and Environmental Restoration activities, though it also continues to support National defense programs.

There are over 400 inactive waste sites at the SRS. The types of contamination at these waste sites range from nonhazardous waste to waste containing both radioactive and hazardous components. The waste sites have been grouped into a number of operable units. Some units include contamination of surrounding subsurface soils and ground water. The contaminants identified include volatile organic compounds (VOCs), heavy metals, pesticides, and radionuclides.

The Defense Waste Processing Facility (DWPF) initiated radioactive operations in March 1996. This facility, the first of its kind in the U.S., will process the high-level portion of 35 million gallons of radioactive waste that are stored in 51 underground waste storage tanks. Current projections are that all SRS high-level waste will be processed at this facility by 2028.

The DWPF is only one component of the high-level waste program at the SRS. Other integral parts of high-level waste operations include evaporators that reduce the volume of waste received from the separations facilities, the in-tank precipitation and extended sludge processing facility that conditions waste for further processing and the saltstone facility that solidifies and disposes of the low-level portion of the waste.

The SRS was placed on the NPL in November 1989. The site currently has an active restoration program focusing on compliance with environmental regulations and cleanup of contaminated sites. This is a particularly challenging task at the SRS because of the high water table in the area and the migration of contaminants from seepage and settling basins, unlined disposal pits, waste piles, burial grounds, and underground storage tanks into the soil and ground water. However, the threat of contaminant migration off-site at levels of public health concern is minimal.

Closure options for waste sites are varied and will be determined on a site-specific basis. Most combine some aspects of waste stabilization, site capping, waste removal, and grading. Ground water remediation activities are being conducted in several areas in accordance with consent orders and agreements. D&D of inactive and surplus facilities is also underway at the SRS. Surveillance and maintenance will continue at many of these facilities after D&D is concluded.



(7) Pantex Plant, Amarillo, Texas

The Pantex Plant is located about 17 miles northeast of Amarillo, Texas and covers approximately 9,100 acres of developed land. The Pantex Plant was constructed by the U.S. Army during World War II as a conventional bomb assembly plant. In 1951, the plant site was turned over to the AEC and updated for nuclear weapons assembly. Currently, the primary mission of the Pantex Plant is to dismantle nuclear weapons no longer required in the Nation's nuclear weapons stockpile. Plutonium pits (the primary explosive nuclear core of the warhead package) are removed and temporarily stored in bunkers at Pantex.

In addition, the site conducts research and development on various explosives in support of weapons design, development, and production engineering for the DOE. Remediation activities are being conducted under the corrective action section of the site RCRA permit.

In 1994, the site was placed on the NPL, thereby requiring remediation under CERCLA authority. The Department is working closely with the regulators to integrate both RCRA and CERCLA requirements to avoid costly duplication of remediation activities. Environmental restoration activities at the site include the assessment of 144 solid waste management units.

Fourteen RCRA Facility Work Plans have been approved by the regulator, and 30 solid waste management units have been closed. Interim Corrective Measures have also been completed, as has an expedited site characterization project for ground water.

(8) Rocky Flats Plant, Golden, Colorado

Established as the Rocky Flats Plant in 1952, the Rocky Flats Environmental Technology Site (RFETS) is located 12 miles northwest of Denver on 6,166 acres of land at the base of the Rocky Mountains. The site itself occupies 384 acres; the rest of the land provides a buffer area. Operations at Rocky Flats have involved fabrication and recovery of plutonium; waste treatment, storage, and shipment for storage or disposal off-site; operating several chemical laboratories; and performing research and development. Components for nuclear weapons were manufactured at Rocky Flats from materials such as plutonium, beryllium, uranium, and alloys of stainless steel using various metal fabricating technologies. Rocky Flats did the necessary foundry and machine shop work to manufacture and assemble the components into their final form. Then, the parts manufactured at the RFETS were shipped to another DOE facility for final assembly.

The Plant manufactured weapons components until 1989, when it was placed on the NPL and all plutonium processing was stopped for health, safety, and environmental reasons. Now, Rocky Flats's primary mission is cleanup.

Plant activities at Rocky Flats have resulted in the generation of a large volume and variety of waste. Rocky Flats has identified 178 waste sites that require remedial action, including 3 off-site reservoirs and 1 land area located off DOE property. The off-site areas may have received contaminated effluent and sediments originating from the Plant. The 178 sites have been grouped into 16 operable units.

Some of the cleanup actions include the following:

- An underground interceptor drainage system that impedes contaminated ground water is currently acting as an interim remedial action to remediate ground water contaminated in the 1960s and 1970s.
- Interception, collection, and treatment of contaminated ground water that is seeping from a hillside where drums were stored in the 1950s and 1960s.
- Remediating the off-site land area and the reservoirs east of the Plant which were contaminated with effluents from the Plant.
- Cleanup of five solar evaporation ponds that, in the 1950s, accepted mixed process waste containing nitrates and acidic waste. Contaminated ground water nearby has been attributed to pond leakage.

Multiple compliance agreements have been developed to aid in the cleanup of the RFETS.

(9) Feed Materials Production Center, Fernald, Ohio



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From 1953 to July 1989, the Fernald Feed Materials Production Center [now known as the Fernald Environmental Management Project (FEMP)] produced uranium feed materials for nuclear reactor fuel as part of the Nation's defense program. The large-scale, integrated plant, which comprises 136 of the 1,050-acre site, was utilized for converting a variety of uranium feed materials containing depleted or slightly enriched uranium into the following: (1) finished uranium metal used in the fuel and target elements of DOE reactors; (2) depleted uranium metal for fabrication into nuclear weapon components at Oak Ridge and Rocky Flats; (3) refined uranium trioxide for eventual use in the DOE gaseous diffusion enrichment plants.

The uranium reactor metal supplied was used in the fabrication of fuel cores for the Hanford N-Reactor, target elements for the Savannah River production reactors, and fuel cores for other reactors operated by the DOE. The facility ceased production in 1989 when its mission changed solely to cleanup and waste management activities; the FEMP was added to the NPL in November 1989.

Since production began in 1953, waste generated as by-products of operations at this facility had been stored and disposed of on-site. Many of the storage and disposal methods used, although believed to be safe and efficient at the time, have proven to be unacceptable by today's standards. Soil and ground water contamination by radionuclides was found both on-site and in adjacent off-site areas. Also of concern were radon releases and the storage of large quantities of low-level radioactive wastes on-site.

Waste at the FEMP includes residues containing uranium and radium, wastewaters, and various solid waste contaminated with uranium and thorium materials, reactive chemicals, oils contaminated with uranium, and organic solvents. More than 20 release sites and an estimated 900,000 cubic yards of waste have been identified. Uranium contamination was found in three off-site private wells near the FEMP; residents using those wells are now being supplied with bottled water by the DOE.

Five operable units have been identified at the FEMP. They are: OU1, the waste pits; OU2, fly ash piles and other waste units; OU3, the former production area/buildings; OU4, storage silos; and OU5, environmental media and the surrounding affected area. RODs have been issued for OUs 1, 2, 4, and 5, and Plant 7 and Plant 4A have been dismantled. An on-site disposal cell will accept approximately 75% of the FEMP cleanup wastes, primarily OUs 2, 3, and 5.

(10) Paducah Gaseous Diffusion Plant, Paducah, Kentucky

The Paducah Gaseous Diffusion Plant is situated in western Kentucky on the southern end of the Ohio River Valley approximately 3 miles south of the Ohio River. The plant is located in a sparsely populated rural area in McCracken County, about 12 miles west of Paducah. The site covers approximately 3,400 acres, 750 of which are in a secured area.

In late 1950, the AEC selected the Paducah site for a new plant to enrich uranium. Construction of the plant was completed in 1954. Enriched uranium is produced at the plant by separating uranium isotopes through the gaseous diffusion process. The enriched uranium produced was historically used for military purposes and as nuclear fuel in commercial nuclear power plants. The Paducah plant was leased in July 1993 to a newly formed Federal Government corporation, the United States Enrichment Corporation. The Department is still responsible for cleaning up the on-site and off-site soil and ground water contaminated with uranium, PCBs, technetium, and trichloroethylene relating to pre-July 1993 activities.

There has been significant on-site and off-site soil, surface water, and ground water contamination at the site. Contaminants of concern include uranium, technetium-99 (a by-product of nuclear fission), polychlorinated biphenyls (PCBs), and trichloroethylene. Approximately 200 waste management units have been identified at the site. There are two significant areas at the site where ground water contamination has been found. One area has been fully characterized and is undergoing interim containment actions (the northwest plume). The other area is undergoing characterization activities (the northeast plume). The site was placed on the NPL in May 1994.

(11) Weldon Spring Quarry/Plant/Pits, St. Charles County, Missouri

The Weldon Spring site is located in St. Charles County, Missouri, approximately 30 miles west of St. Louis. The site consists



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of two geographically distinct areas: (1) a 217-acre chemical plant area, and (2) a 9-acre limestone quarry about 4 miles south-southwest of the chemical plant area. Initially, the site was used by the U.S. Army in the 1940s to produce explosives. In the 1950s and 1960s, the AEC used the site for processing uranium and thorium ore concentrates.

Radioactive and chemical waste was disposed of at the chemical plant site throughout the 1950s and 1960s. In addition, waste was disposed of in the quarry by both the Army and the AEC from the 1940s through the 1960s. Chemical and radioactive contamination has been found in the chemical plant buildings, surface water, soil, and upper aquifer ground water. The EPA listed the quarry on the NPL in 1987, and the chemical plant area was added in 1990.

From 1989 to 1995, Weldon Spring dismantled all chemical plant buildings and completed operation of the waste treatment pilot plant. Under the Weldon Spring Site Remedial Action Project (WSSRAP), the DOE is conducting a comprehensive remedial action program, including long-term management of radioactive waste. Cleanup activities are directed toward the quarry, the chemical plant, and contaminated ground water, both on- and off-site.

(12) Brookhaven National Laboratory, Upton, New York

The Brookhaven National Laboratory (BNL) is a multipurpose research and development laboratory that directs scientific and technical efforts, including physics, life sciences, and nuclear medicine research. The Laboratory is located on Long Island approximately 60 miles east of New York City, and occupies about 8.3 square miles of mostly wooded land. The U.S. Army used this 5,260-acre site as a post during World Wars I and II. Today, BNL is a design, construction, and operations center for large research facilities (e.g., particle accelerators, nuclear reactors, and synchrotron storage rings). These facilities conduct research in high-energy and nuclear physics, chemistry, biology, nuclear medicine, medical applications of nuclear technologies, and energy-related life and environmental sciences.

On-site ground water and soil contamination have been detected over an EPA-designated sole-source drinking water aquifer. Ground water and soil sampling have been initiated to assess contamination levels. ER activities at BNL are related to ground water remediation and protection at sites identified as known or potential areas of soil or ground water contamination. These areas of contamination are the result of hazardous and radioactive discharges, including VOCs and H-3, and of past on-site disposal of hazardous and radioactive waste in landfills. Twenty-eight areas of concern have been identified at BNL through an intensive document and record search, employee interview, and site investigation process. These 28 areas of concern have all been earmarked as needing remedial action. Additionally, the Brookhaven Graphite Research Reactor is scheduled for D&D. The BNL was placed on the NPL in November 1989.

(13) Lawrence Livermore National Laboratory, Livermore, California (2 sites)

The Lawrence Livermore National Laboratory (LLNL) occupies two sites in northern California. The Main Livermore Site encompasses an area of approximately 1 square mile and is located 40 miles east of San Francisco, just east of the City of Livermore. Site 300, which comprises approximately 11 square miles, is located 15 miles southeast of the Main Livermore Site.

At the Main Livermore Site, Navy operations in the 1940s and subsequent laboratory handling and storage of hazardous materials resulted in the release of contaminants in soil and ground water on-site and the migration of contaminated ground water off-site. Operations at Site 300 involved the processing, testing, and deactivating of explosives and experiments in which weapons components were subjected to environmental stresses. Some of these activities resulted in contaminated soil, ground water, or both. Both sites have wastewater and petroleum tank systems and transformers that must be upgraded to meet local, state, and federal requirements. Both sites are on the NPL.

The Laboratory is operated by the University of California for the DOE and currently conducts nuclear weapons research, design, and testing, as well as basic research in physics, chemistry, life sciences, and nuclear engineering. The LLNL's current mission



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is to serve as a national resource for science and engineering technology focused on national security, energy, the environment, biomedicine, and science and mathematics education. The Laboratory has particular strengths in areas such as nuclear science and technology, space technology, biology and biotechnology, environmental science and technology, and earth and atmospheric science.

Major programs include research, development, and test activities associated with all phases of nuclear weapon life-cycle and related tasks; verification and control technology; magnetic fusion energy; laser fusion and laser isotope separation; biomedical and environmental sciences; and applied energy technology. The LLNL's Site 300 facilities include a high-explosive testing facility and its support units.

The Livermore main site was added to the NPL in July 1987, and Site 300 was added in August 1990. The major ER Program concern at LLNL involves organic solvents in the ground water under the Livermore site. Contaminated ground water has spread off-site, extending approximately 2,000 feet, but pump and treat systems are in place to reduce source contamination and control plume (a mobile volume of contamination) migration. In addition, soils are contaminated with fuel hydrocarbons. The primary Environmental Restoration (ER) Program activity involves assessing and cleaning up volatile organic compounds (VOCs), high explosives, and H-3 contamination in the surrounding ground water and soil.

At the Livermore Main Site, five treatment facilities have extracted over 175 million gallons of contaminated ground water and removed about 72 kilograms of VOCs. In addition, Treatment Facility F has treated 15.3 million gallons of ground water and 2.7 million cubic feet of soil using dynamic underground stripping. This project extracted vapor that contained 10,200 gallons of gasoline. In August 1995, the regulatory agencies approved the closure of the vapor extraction system because the cleanup had met the requirements in the CERCLA ROD; vadose zone remediation was closed. Hydraulic control of the western off-site plume also was established, resulting in a dramatic decrease in the off-site VOC concentrations.

(14) The Laboratory for Energy-Related Health Research/Old Campus Landfill, Davis, California

The Laboratory for Energy-Related Health Research (LEHR) consists of several DOE-owned buildings located on a 15-acre site on the campus of the University of California at Davis (UCD). The LEHR consisted primarily of two animal hospitals, laboratory and support buildings, waste treatment facilities, and numerous dog pens. The site property, which is leased from the University by the DOE, is surrounded by other campus research facilities and private farms. LEHR was established by the AEC to conduct research on the long-term health effects of exposure to low levels of radiation. From 1960 to 1988, the laboratory was specifically used to study the biological effects of continuous whole body exposure to bone-seeking radionuclides (i.e., Sr-90 and Ra-226) on research animals. In 1988, the Department terminated research on the health effects from chronic exposure to radionuclides and closed the Laboratory. The Laboratory's current mission is to conduct D&D, site remediation, and other related activities so that the facilities can be returned to the University.

During the nearly 30 years of AEC/DOE-funded operations, LEHR generated and disposed of radioactive, biologic, and chemical wastes, as well as municipal and laboratory wastes. Research activities resulted in contamination of animal pens and cages, a tank trailer, and five buildings. These activities also generated radioactive sludge wastes. Radioactive wastes were buried in shallow, unlined trenches and pits that resulted in soil contamination. In addition, two separate liquid radioactive waste treatment and discharge systems (i.e., septic tanks and sludge settling tanks) were in operation at LEHR that potentially discharged radionuclides to leach fields on-site. Some chemical and radioactive contaminants may have reached the ground water as a result. Furthermore, leachate from the old campus landfill on the LEHR site is contaminating area ground water. LEHR was added to the NPL in May 1994, due to ground water contamination detected during preliminary site investigations of ground water and soil.

(15) W.R. Grace/Wayne Interim Storage Site, Wayne Township, New Jersey

The Wayne site is located in a highly developed area of northern New Jersey approximately 20 miles north-northwest of Newark, New Jersey and 36 miles northwest of New York City. From 1948 through 1971, Rare Earths, Inc. and, later, W.R. Grae



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Company processed monazite sand at the site to extract thorium and other metals. These metals were used to manufacture industrial products, such as mantles for gas lanterns.

In 1954, Rare Earths received a license from the AEC to continue thorium processing operations. The Davison Chemical Division of W.R. Grace acquired the facility in 1957, and thorium processing activities continued until 1971. Wastes and residues from the processing operations included thorium ore tailings, yttrium (a metallic element) sludges, and sulfate precipitates. When processing ceased in 1971, the facility was licensed for storage only. In 1974, the Wayne site was partially decontaminated by W.R. Grace. Some buildings were razed; the rubble and processing equipment were subsequently buried on the property. The remaining buildings were decontaminated, and the disposal areas on the site were covered with clean fill material. The storage license for the W.R. Grace plant was terminated in 1975 following site decommissioning. The site was placed on the NPL in September 1984.

Contamination at the 6.4-acre storage site and numerous vicinity properties (VPs) resulted from commercial thorium processing operations over a period of nearly 25 years. During this period, process wastes from the thorium operations were buried on-site and various liquid effluent wastes were released to local storm drains. The storm drains empty into Sheffield Brook, which periodically overflows its banks during heavy rainfall. This has caused contamination to spread to nearby low-lying areas. In addition, an interim storage pile contains processing wastes and radioactively contaminated soil and building rubble from previous cleanup actions.

The DOE was assigned responsibility for cleaning up the site in 1984 under a congressional mandate. The Wayne site is used specifically as an interim storage site for contaminated material removed during cleanup of the site and the associated VPs. The remedial investigation for the site was completed in 1992. Complete remediation is expected by the year 2011.

All of the sites discussed in the previous section are part of the DOE's EM Program. The EM Program also includes several other NPL sites. Although the EPA does not list these sites in the Federal Facilities Section of the NPL (40 CFR Part 300, Appendix B), the sites are listed in the General Superfund Section. Congress has assigned responsibility for remediating these sites to the DOE. As a result, EM is conducting remediation activities at these sites.

(16) St. Louis, Missouri (3 sites)

The St. Louis Airport Storage Site and Vicinity Properties - The St. Louis Airport Storage site is located immediately north of Lambert-St. Louis International Airport in St. Louis County, approximately 15 miles from downtown St. Louis and 11 miles northwest of the St. Louis Downtown site. In 1946, the Manhattan Engineer District (MED, the predecessor agency of the AEC) acquired the 21.7-acre tract to store radioactive residues from Federal uranium ore processing activities conducted at the St. Louis Downtown site during and after World War II.

Most of the stored residues were sold and removed from the site in 1966 and 1967. On-site structures were razed, buried at the site, and covered with clean fill dirt. However, buried deposits of various radionuclides remained on the site. In 1973, the Federal Government and the City of St. Louis agreed to transfer ownership of the site, with full disclosure of site conditions, from the AEC to the St. Louis Airport Authority. The VPs (which are not owned by the DOE) consist of former transport roads and approximately 78 adjacent properties.

The Latty Avenue Site - The Latty Avenue site consists of 11 acres of properties located north of the St. Louis Airport, including the Hazelwood Interim Storage Site (HISS) and six contaminated VPs. In 1966, the radioactive ore residues and process wastes that had been stored at the St. Louis Airport Storage site were purchased by a private company, moved to the HISS, and placed in storage from 1966 to 1973 under an AEC license. Residual radioactive surface contamination in excess of DOE guidelines was later discovered in and around the site buildings and in the soil. Congress authorized the DOE to cleanup the site in 1983. Final remedial action is scheduled to begin in 1998, and remediation is expected to be completed within the next 15 years.

(17) Maywood Chemical Works, Maywood/Rochelle Park, New Jersey



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The Maywood Chemical Works (MCW) was constructed in 1895. From 1916 through 1956, the MCW extracted thorium and other metals from monazite sand for use in manufacturing gas lantern mantles and other industrial products. During this period, wastes from the thorium ore processing operations were pumped to diked areas west of the plant. Some of these process wastes were subsequently removed for use as mulch and fill on nearby properties. These activities contaminated more than 80 local properties with radioactive thorium in Maywood, Lodi, and Rochelle Park, New Jersey. The disposal areas were later partially covered by the construction of NJ Route 17.

In 1954, the AEC issued a license allowing the MCW to continue activities involving radioactive materials. In 1956, after approximately 40 years of production, MCW stopped processing thorium, and, in 1959, MCW was sold to Stepan Company. Although cleanup of residual thorium wastes began in 1963, on-site waste burial continued until 1968.

Congress assigned responsibility for cleanup of the Maywood site to the DOE in 1983. The DOE negotiated access to an 11.7-acre portion of the Stepan property for use as a temporary storage site (the Maywood Interim Storage Site) for contaminated waste from the VPs. In 1985, the interim storage area was acquired by the DOE. A remedial investigation was conducted during 1991 and 1992, and remediation is expected to be completed within the next 15 years.



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(18) Maxey Flats Nuclear Disposal Site, Hillsboro, Kentucky

Maxey Flats was opened in 1963 as a commercial nuclear waste burial site. The site covers 280 acres and was used by the DOE and other waste generators for disposing low-level radioactive materials. Maxey Flats was closed in 1977 due to water management problems: Leachate (i.e., liquid and suspended contaminants that have percolated or drained through the buried waste) was found to contain H-3 and other radioactive substances. The site was placed on the NPL in 1986.

As one of the approximately 800 designated potentially responsible parties, the DOE is financially responsible for about 40 percent of the total remediation cost. The Record of Decision for the site was signed in 1991. The CERCLA consent decree negotiations were completed in 1995, and cleanup is underway.



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(Any reasonable paraphrase of the following is acceptable.)

Hazards to the repairman involve exposure to the fingers and hands. Because he was very close to the beam while it was on, it is very likely that his fingers or hands could have actually been in the beam for a short time. The repairman may suffer some acute effects of radiation exposure to his fingers and hands, as well as be at risk for cancer in the area exposed. The operator was standing about one meter away from the beam. He may or may not have received an exposure, depending on the configuration of the system. If exposed, it is likely that only a portion of his body was exposed, since the leakage or scatter beams (the main sources of exposure) would be fairly small in diameter. The operator is probably not going to suffer any acute effects, and his risk of long-term effects will depend on the level of exposure.

Some of the follow-up actions that should be taken by the supervisor and contractor management include:

- Immediately process any personnel monitoring devices that the workers were wearing. The dosimetry processor should be notified of the energy range of the x-rays that may have caused the exposure.
- Interview both workers to determine exactly what happened, in what sequence, and when. The workers should be asked to retrace their movements to the best of their knowledge. It is important that this action be performed as soon as possible after the incident so that the workers' memories are still fresh. It is helpful for two interviewers to document the workers' stories so that discrepancies can be resolved before a final report is written.
- Enact a time-motion study of the workers' actions. Once this has been accomplished, management should obtain radiation exposure measurements to assess worker dose. The measurements should be made with an instrument capable of measuring high exposure rates of low-energy x-rays. Corrections may also need to be made to the instrument reading if the detector chamber is large relative to the size of the beam.
- Refer the workers for medical follow-up. Dosimeter results or radiation measurements may be helpful to the examining physician.
- Evaluate the incident from a management perspective relative to regulatory requirements, notifications, root cause, ALARA, and prevention of future similar incidents.

The most pertinent standard is ANSI N43.2, *Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment*. Probably the most significant deviation from requirements of the standard involves a procedural requirement to ascertain that the tube is off before performing maintenance or modifications. Section 6.5.1 of the standard states, "No operation involving removal of covers, shielding materials, or tube housings; or modifications to shutters, collimators, or beam stops shall be performed without ascertaining that the tube is off and will remain off until safe conditions have been restored. The main switch, rather than safety interlocks, shall be used for routine shutdown in preparation for repairs." Both the repairman and the operator failed to pull the main power switch before repairs.

Section 5.2.2.1.4 requires a visual indicator (light) at the switch as well as at the tube housing. There may have been a visual indicator, but if so, it is unclear why the repairman would not have seen it before



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resuming repair work. Instead, he realized the beam was on by accidentally touching the cooling jacket of the tube. A visual indicator at the tube housing may have prevented his fingers and hands from receiving an unnecessary exposure.

Once dosimeter results are available, a dose assessment can be performed on the workers. The dose assessment should be based on both the dosimeter results and the incident reconstruction data. Dose assessments will indicate if dose limits were exceeded.



4. SUGGESTED ADDITIONAL READINGS AND/OR COURSES

- Bush, W.R., *Assessing and Controlling the Hazard from Tritiated Water*, AECL-4150, Atomic Energy of Canada LTD., Chalk River, Ontario, 1972.
- Cember, Herman, *Introduction to Health Physics*, 3rd ed., McGraw-Hill, 1996
- EG&G Mound Applied Technologies, *Health Physics Manual of Good Practices for H-3 Facilities*, MLM-3719, Draft, Miamisburg, Ohio, December 1991.
- Gollnick, Daniel A., *Basic Radiation Protection Technology*, 3rd ed., Pacific Radiation Corporation, 1994.
- International Atomic Emergency Agency, *Safe Handling of H-3*, IAEA- 324, Vienna, Austria, 1991.
- Lubenau, Joel O., et al. (1969). *Analytical X-ray Hazards: A Continuing Problem*. Health Physics, Vol. 16, pp. 739-746.
- National Council on Radiation Protection and Measurements (NCRP) 47, *H-3 Measurement Techniques*, 1976.
- T.B. Rhinehammer and P.H. Lamberger (eds.), *H-3 Control Technology*, WASH-1269, Monsanto Research Corporation, Miamisburg Ohio, 1973
- Weigenburg, Irving J., et al. (1980). *Injury Due to Accidental Exposure to X-rays from an X-ray Fluorescence Spectrometer*. Health Physics, Vol. 39, pp. 237-241.
- DOE-HDBK-1079-94, *Primer on H-3 Safe Handling Practices*.
- DOE-HDBK-1108-97, *Radiological Training for Accelerator Facilities*.
- DOE Order 5000.3B, *Occurrence Reporting and Processing of Operations Information*.
- DOE Order 5400.5, *Radiation Protection of the Public and the Environment*.
- DOE/EH-0256T, *Radiological Control Manual*.
- DOE/EM-0226, *Closing the Circle of the Splitting of the Atom*, Office of Environmental Management, January 1996.
- DOE/EH-0425, *Plutonium Facilities Training Material*
- DOE/EM-0246, *Decommissioning Resource Manual*.
- DOE/EM-0142P, *Decommissioning Handbook*.
- Implementation Guide G-10 CFR 835/C3, 65, *Radiation-Generating Devices*.
- 10 CFR 835, *Occupational Radiation Protection*.
- 10 CFR 34, *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations*.
- ANSI N-43.2-1988, *X-Ray Diffraction and Fluorescence Analysis Equipment, Radiation Safety*.
- ANSI N-43.3-1993, *General Radiation Safety-Installations Using Non-Medical x-ray and Sealed Gamma-Ray Sources, Energies up to 10MeV*.
- *An Introduction to Nuclear Weapons*, Samuel Glasstone and Lelie M. Redman, U.S. Atomic Energy Commission, WASH-1037, Secret Security Classification required
- *Nuclear Explosive Training Manual*, DOE Albuquerque Operations Office, Secret Security



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Classification required, (NESD, 505/845-5902)

- *Caging the Dragon - The Containment of Underground Nuclear Explosions*, James Carothers, Lawrence Livermore National Laboratory, DOE/Defense Programs, Defense Nuclear Agency DOE/NV-388, DNA-TR-95-74, unclassified, (423/576-8401).