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GUIDE TO RADIOLOGICAL PROTECTION IN PLUTONIUM FACILITIES - VOL 3 OF 3

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Exam Preview:

1. According to the reference material, ^{116m}In has a __-min half-life and releases a 1-MeV beta (maximum energy) and a 1.3-MeV gamma (80% of the time).
    a. 22
    b. 39
    c. 54
    d. 85
2. According to the reference material, the use of neutron activation of keratin in hair is another method to estimate absorbed dose for workers involved in a criticality accident
    a. True
    b. False
3. According to the Department of Energy Plutonium Vulnerability Analysis Study, excluding the classified mass of plutonium contained in nuclear weapon pits at the Pantex Plant in Texas, these sites held __ metric tons of plutonium.
    a. 26
    b. 34
    c. 41
    d. 50
4. According to the reference material, sanitary waste is by far the least costly and easiest to dispose of. Liquid sanitary waste is disposed of in sanitary sewerage systems or septic systems.
    a. True
    b. False

5. Using Table 8.1. Waste Types, and the surrounding reference material, which of the following waste types matches the description "refers to waste materials containing elements with atomic numbers greater than 92. These elements are generally alpha-emitting radionuclides that decay slowly?"
   a. HLW
   b. LLW
   c. MW
   d. TRU
6. According to the reference material, ion exchange is one of the least useful waste treatment techniques.
   a. True
   b. False
7. According to the reference material, purification by reverse osmosis is highly effective on relatively pure water streams. The result is generally 80% to __% of the influent water released as pure water, with the remainder containing all of the contaminants.
   a. 90
   b. 93
   c. 99
   d. 85
8. According to the reference material, the basic public dose limits for exposure to residual radioactive material in addition to natural background exposures is a ___-mrem effective dose equivalent in a year from all sources and pathways.
   a. 100
   b. 500
   c. 1,000
   d. 10,000
9. According to the reference material, residual concentrations of radionuclides in air shall not cause members of public to receive an effective dose equivalent greater than 100 mrem in one year
   a. True
   b. False
10. According to the reference material, generic guidelines for thorium and radium are 5 pCi/g averaged over the first __ cm of soil below the surface.
    a. 5.0
    b. 7.5
    c. 12.5
    d. 15

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Foreword

This Technical Standard does not contain any new requirements. Its purpose is to provide information on good practices, update existing reference material, and discuss practical lessons learned relevant to the safe handling of plutonium. U.S. Department of Energy (DOE) health physicists may adapt the recommendations in this Technical Standard to similar situations throughout the DOE complex. The Standard provides information to assist plutonium facilities in complying with Title 10 of the Code of Federal Regulations (CFR), Part 835, Occupational Radiation Protection. The Standard also supplements the DOE 10 CFR 835 Implementation Guide, DOE Orders, and DOE standard, DOE-STD-1098-2008, Radiological Control, (RCS) and has as its sole purpose the protection of workers and the public from the radiological hazards that are inherent in plutonium storage and handling.

This Standard uses the word "shall" to identify a required practice or the minimum acceptable level of performance. The word "should" is used to identify good practices (preferred practices) recommended by this Standard. The word "may" is used to identify permitted practice (neither a requirement nor a recommendation).

This Standard includes provisions in the 2007 amendment to 10 CFR 835. This amendment updated the dosimetric terms and models for assessing radiation doses, both internal and external. Of particular interest for this Standard, the biological transportability of material is now classified in terms of absorption types; F (fast), M (medium) and S (slow). Previously this was classified in terms of material class; D (days), W (weeks) and Y (years). Throughout this Standard, discussions of previous studies describing the biological transportation of material in the body will continue to use D, W and Y, as appropriate. Discussions of other requirements which have not amended their dosimetric terms and models continue to use the older terminology.

This Standard does not include every requirement applicable to every plutonium facility. Individuals responsible for implementing Radiation Protection Programs at plutonium facilities need to be knowledgeable of which requirements (contractual or regulatory) are applicable to their facility.

Copies of electronic files of this Technical Standard may be obtained from either the DOE Radiation Safety Home Page Internet site (http://www.hss.energy.gov/HealthSafety/WSHP/radiation/ts.html) or the DOE Technical Standards Program Internet site (http://www.hss.doe.gov/nuclearsafety/techstds/standard.html).

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7.0 NUCLEAR CRITICALITY SAFETY

This chapter will emphasize present-day criticality concerns from the standpoint of what health physics personnel need to know to ensure that the DOE mission is accomplished in a safe and cost effective manner. It provides an overview of the administrative and technical elements of current nuclear criticality safety programs. It does not provide a definitive discourse on nuclear criticality safety principles or repeat existing guidance. For health physics personnel who require a greater understanding of nuclear criticality safety, the references contained here provide a source of such detailed requirements and information.

DOE Policy 420.1, Department of Energy Nuclear Safety Policy, documents DOE's nuclear safety policy (DOE, 2011f).

Nuclear criticality safety issues at DOE facilities historically have been concerned with manufacturing plutonium, processing plutonium into weapon components, and storing weapon components and weapons in safe arrays. With DOE's newly identified mission of concluding much of the plutonium production and decommissioning of production reactors and processing facilities, today's nuclear criticality safety concerns have changed. While the historic nuclear criticality safety issues remain with the storage of weapons and associated components, current concerns include the disassembly of weapons, processing, and disposition of unique plutonium materials (commonly referred to as “legacy materials”), and decommissioning of production reactors and processing facilities.

Radiation protection personnel should understand nuclear criticality principles and the impact of these principles on radiological conditions that result from the processing, handling, and storage of fissionable materials. Radiation protection personnel provide an additional knowledgeable resource to help recognize workplace situations that might lead to the violation of a nuclear criticality control parameter that could contribute to an inadvertent nuclear criticality event. There have been occasions in the history of the nuclear industry when radiation protection personnel have observed and stopped unsafe actions by facility personnel that, if allowed to continue, might have resulted in an inadvertent nuclear criticality. Radiation protection personnel shall also be aware of the potential impact of actions that may be routine for normal radiation protection practice, but which could result in the violation of a nuclear criticality control parameter. Finally, radiation protection personnel provide significant support in emergency response actions should an inadvertent nuclear criticality occur. These actions include use of emergency instrumentation, accident dosimetry, radiological dose assessment, and recovery.

This chapter reviews (1) nuclear criticality safety regulations and standards applicable to DOE facilities, (2) criticality control factors, (3) past criticality accidents and associated lessons learned, (4) roles, responsibilities, and authorities of health physics staff with regard to nuclear criticality safety, (5) the content of an acceptable nuclear criticality safety program, and (6) a summary of the criticality safety issues identified in DOE/DP-0123T, Assessment of Plutonium Storage Safety Issues at Department of Energy Facilities (DOE, 1994a).

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7.1 REGULATIONS AND STANDARDS

Nuclear criticality safety program requirements for DOE facilities are presented in DOE Order 420.1C (DOE, 2012b). The order also addresses nuclear safety design criteria, fire protection, natural phenomena hazards mitigation and the cognizant system engineer program.

DOE Order 420.1C requires that the criticality safety program describe how the contractor will satisfy the requirements of the ANSI/ANS-8 consensus nuclear criticality safety standards in effect as of the date of DOE Order 420.1C, including why any recommendation in applicable ANSI/ANS-8 standard is not implemented.

7.2 CRITICALITY CONTROL FACTORS

For a criticality accident to occur, there has to be a critical mass of fissionable material. The critical mass is a function of the radionuclides in the material as well as its density, chemical and physical form, shape, and surroundings (i.e., moderators, reflectors, neutron absorbers). Nuclear criticality safety is achieved through the control over both the quantity and distribution of fissile materials and other materials capable of sustaining a chain reaction as well as the control of the quantities, distributions, and nuclear properties of all other materials with which fissile materials are associated. For new facilities, DOE requires that design considerations for the establishing controls should be mass, density, geometry, moderation, reflection, interaction, material types, and nuclear poisons (neutron absorbers). The use of administrative controls should be minimized (DOE, 2016a).

Nuclear criticality control factors can be classified as technical (e.g., geometry controls and mass limitation controls) or administrative (e.g., operating procedures).

7.2.1 Technical Control Factors

Plutonium isotopes include ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu. Although a tremendous amount of criticality safety work centered around uranium and its manufacture at Oak Ridge. This standard addresses plutonium facilities. All these radionuclides are fissionable materials; however, ^{239}Pu and ^{241}Pu are referred to as fissile materials, a subset of fissionable materials. Fissile materials are capable of sustaining a neutron chain reaction with thermal neutrons and fast neutrons and, as such, have lower critical masses than other plutonium isotopes.

Single-parameter limits for plutonium solutions, oxides, and metals are presented in ANSI/ANS-8.15 (ANSI, 1981) and are summarized in Table 7.1. A single-parameter limit means that if any one of the parameters for a given material is maintained less than its limit, then a criticality event is impossible. For example, for a $^{239}Pu(NO_3)_4$ solution, as long as the ^{239}Pu mass in the solution is less than 0.48 kg, the other parameters can exceed their limits (e.g., the solution concentration could be greater than 7.3 g/L) and a criticality incident is not possible.

For plutonium solutions and metals in an isolated system, use of favorable geometry is the preferred method of criticality control. An isolated system is far enough removed from other systems such that neutron leakage from a nearby system will not contribute to the likelihood of a criticality excursion. Where geometry control is not feasible, the preferred order of controls is (1) other passive engineering controls (e.g., mass control), (2) active engineering controls, and (3) administrative controls

Other technical control factors used to control nuclear criticality risks include density controls, spacing controls (sometimes referred to as interaction), neutron absorbers, moderation controls, and neutron reflection. Spacing controls become particularly important in the storage and transport of fissionable materials.

7.2.2 Double Contingency

The concept of double contingency in nuclear criticality safety applies technical control parameters to ensure nuclear criticality safety. The following table identifies some single parameters.

Table 7.1. Subcritical, Single Parameter Limits for Plutonium Solutions and Metals (AMSI, 1983b)

	Plutonium Solutions and Metals			
Parameter	$^{239}Pu(NO_3)_4$	Metallic ^{239}Pu	$^{239}PuO_2$ (a)	$^{239}PuO_2$ (b)
Mass of fissionable nuclide, kg	0.48	5.0	10.2	27
Diameter of cylinder of Solution, cm	15.4	-	-	-
Volume of solution, L	7.3	-	-	-
Concentration of fissionable Nuclide, g/L	7.3	-	-	-
Cylinder, diameter, cm	-	4.4	7.2	12.6
Slab thickness, cm	5.5	0.65	1.4	2.8
Maximum density for which Mass and dimension limits are valid, g/cm^3	-	19.82	9.92	-

(a) Oxides containing no more than 1.5% water by weight at full density.
(b) Oxides containing no more than 1.5% water by weight at no more than half density.

Double contingency requires that process designs incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a nuclear criticality accident is possible.

Protection, or defense in depth, should be provided by either (a) the control of two independent process parameters (which is the preferred approach, if practical) or (b) a system of multiple controls on a single parameter. The basis for selecting either approach should be fully documented.

The two parameters that are controlled in the double contingency analysis process shall not be related by common mode failures. Judgment is required in determining whether two events are related and, consequently, whether they represent two contingencies or a single contingency. For example, exceeding a storage limit and then flooding an area with water would constitute two independent events. However, a fire followed by the flooding of a storage area with fire suppression water would constitute a single event.

The double contingency principle should be applied to all nuclear criticality safety analyses for processes, systems and equipment, storage, and transportation of fissile materials. Should contingencies be determined to be related, efforts are to be made to separate the contingencies.

7.2.3 Administrative Control Factors

Administrative control factors are the combination of personnel, programs, plans, procedures, training, audits and reviews, and quality assurance practices which are used to administer a nuclear criticality safety program. Administrative controls are used in addition to engineered controls or design features to ensure nuclear criticality safety of facility operations. Administrative control factors are outlined in ANSI/ANS-8.19 (ANSI, 2005). An effective nuclear criticality safety program requires a joint effort by managers, supervisors, plutonium workers, and nuclear criticality safety staff and relies upon conformance with operating procedures by all involved personnel. The following sections describe the key requirements of a nuclear criticality safety program from ANSI/ANS-8.19.

7.2.3.1 Nuclear Criticality Safety Program

Management shall develop a nuclear criticality safety policy and ensure that it is distributed to fissile material workers. They also delegate authority to implement the policy, monitor the nuclear criticality safety program, and periodically participate in audits of the program. Supervisory staff shall ensure that nuclear criticality safety procedures are written and that staff is trained in those procedures. The nuclear criticality safety staff shall provide technical guidance for the design of equipment and processes and for the development of operating procedures. A nuclear criticality safety evaluation shall be performed by the nuclear criticality safety staff before starting a new operation with fissile materials or before an existing operation is changed. An independent evaluation of the technical adequacy of the nuclear criticality safety program shall also be performed periodically.

7.2.3.2 Nuclear Criticality Safety Organization

Like the radiation protection program, the nuclear criticality safety organization should have a reporting line to the highest level of facility management independent of operations. The nuclear criticality safety organization shall have the responsibilities and authorities of its staff clearly delineated and communicated to the other facility personnel. Lines of interaction and interfaces with other facility organizational components should be clearly defined, both organizationally and procedurally. In any case, the responsibility for nuclear criticality safety should be assigned in a manner that is compatible and consistent with the other safety disciplines. The organization should also contain an independent nuclear criticality safety review committee and have access to consultants to assist in the conduct of the criticality safety program.

7.2.3.3 Plans and Procedures

Facility nuclear criticality safety plans and procedures are important components of the overall facility operation. These documents provide the means by which the program is conducted and prescribe how nuclear criticality safety is to be achieved. These plans and procedures identify how both the administrative activities are to occur and how the technical aspects of nuclear criticality safety analysis are conducted. The purpose of procedures is to facilitate the safe and efficient conduct of operations. The processes of procedure development, review, training, and approval have sufficient controls to ensure that nuclear criticality concerns are properly addressed. These controls include the periodic review and reaffirmation of these procedures, ensuring that procedure deviations are properly investigated and reported to facility management and, if appropriate, to DOE. The controls should also mitigate the possibility of such deviations recurring.

Procedures should exist that address the determination and posting of nuclear criticality safety parameters. These procedures should include a description of how the limits are to be determined and how workstations are to be posted as to form, geometry controls, mass limits, moderator limits, etc.

Inspections and audits are performed to assess the success of the nuclear criticality safety program. The audits shall be performed by qualified individuals who are independent of the operation. They are conducted to verify that operating procedures and other safety standards are being followed and to identify any weaknesses in the nuclear safety program. Deficiencies identified in these inspections and audits shall be formally addressed, tracked, reported, and resolved.

ANSI/ANS-8.20 (ANSI, 1991) provides guidance for development of nuclear criticality safety training plans and procedures for personnel working with or near fissile materials. This program and its associated procedures should describe the program, training requirements, recordkeeping, content, responsibilities, and objectives of a facility nuclear criticality safety program.

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7.3 CRITICALITY ACCIDENT EXPERIENCE

Criticality accidents, sometimes called criticality excursions, can either be short-duration pulse-type excursions or continuous excursions. In the history of plutonium handling and processing, there have been five criticality accidents involving plutonium materials. Three of the accidents occurred during research activities and the other two accidents during plutonium-processing operations. The two processing accidents are reviewed in this section.

7.3.1 Types of Criticality Accidents

In a pulse-type criticality accident, there is an initial pulse of typically 10^{15}-10^{17} fissions over a short time-period (less than 1 sec), sometimes following by additional lower-intensity pulses. In a fissionable material solution, the pulse or spike is terminated by the heating and consequent thermal expansion of the solution and by bubble formation that serves to reconfigure the fissile mass into a noncritical configuration (Paxton, 1966). If the initial pulse results in a loss of solution from the container (e.g., by splashing) or redistribution of material, the criticality event may conclude without further pulses. However, if there is no loss of material as the solution cools, it may form a criticality mass once again and pulse with slightly lower fission yield (Paxton, 1966).

Criticality accidents can result in lethal doses of neutron and gamma radiation at considerable distances from the accident site (on the order of tens of meters). There can also be high beta-gamma residual radiation levels from fission products after the excursion is concluded. The heat generated during the excursion can melt parts of the system that held the fissionable material (Moe, 1988).

Moe (1988) reviewed estimations of prompt radiation doses from excursions in a moderated system and a metallic system, as well as dose rates from residual contamination left by a criticality excursion. Assuming a burst of 10^{18} fissions in an unshielded, water-moderated system, the total absorbed dose is estimated to be >600 rad up to 6 m and >100 rad up to about 15 m. The gamma/neutron ratio of the total absorbed dose was 2.8. For an unmoderated configuration, the gamma/neutron absorbed dose ratio was 0.1. In general, for a moderated system, the gamma dose would be expected to be higher than the neutron dose and, for a metal system, the neutron dose would be expected to be higher than the gamma dose.

Moe (1988) noted that for an excursion of $>10^{18}$ fissions, dispersion of the fissile material and the fission products would occur, resulting in heavy local contamination and a subsequent high residual dose rate. This dose rate was estimated at >1000 rad/h at 100 ft shortly after the burst and >10 rad/h at 30 ft an hour after the burst. This is the basis for instructing workers to immediately vacate the work area when the criticality alarm is sounded. Seconds can save significant dose, if not from the excursion itself, then from any residual radiation that is in the area.

7.3.2 Summary of Past Criticality Accidents

Stratton summarized five criticality accidents involving plutonium prior to 1967 (Stratton, 1967). Three of the accidents involved plutonium in solutions, with the other two involving metallic forms. Three of the accidents involved early research activities and the other two were plutonium-processing accidents. Summaries of these two accidents follow as derived from Stratton (1967) or Paxton (1966). No criticality accidents have occurred regarding mechanical processing, storage of plutonium materials, or transportation of plutonium materials.

7.3.2.1 Los Alamos Accident - December 30, 1958

A nuclear criticality accident occurred on December 30, 1958, at the Los Alamos Scientific Laboratory, killing one worker and overexposing two other workers. The criticality occurred in a 225-gal, 38-in.-diameter stainless steel tank, with a thick organic layer containing 3.27-kg plutonium floating on a dilute aqueous solution of 60-g plutonium in 330 L. The tank was cylindrical and water-reflected. The tank contents were stirred, mixing the contents into a critical configuration. Microbubbles, thermal expansion, and continued mixing of the tank eliminated the critical configuration. The excursion consisted of a single pulse of 1.5×10^{17} fissions. The operator near the tank received a lethal dose of 12,000 rem (±50%), while two workers who assisted the operator received doses of 134 rem and 53 rem. The tank was supposed to have only 0.125 kg of plutonium; however, a gradual accumulation of solids during the 7.5-year operating history of the plant resulted in 3.27-kg plutonium in the tank.

7.3.2.2 Hanford-Recuplex Plant Accident - April 7, 1962

On April 7, 1962, a criticality accident occurred at a multipurpose plutonium-recovery operation at the Recuplex Plant, Hanford, Washington. During a clean-up operation, about 46 L of solution containing 1400- to 1500-g plutonium was directed into a 69-L glass transfer tank that led to the criticality accident. The tank was 93% full and unreflected. Solutions in the tank generally contain only a fraction of a gram per liter; however, in this situation apparently the solution was drawn from a sump through a temporary line that was being used for cleanup. The excursion had an initial pulse of about 10^{16} fissions. Following this spike, the tank was fissioning for 37.5 hours with the power level steadily decreasing (Stratton, 1967). The total yield of the accident was about 8.2×10^{16} fissions distributed over a 37-hour time period with about 20% in the first half-hour. Three workers in the vicinity of the tank during the initial spike received doses greater than regulatory limits. One worker about 5 to 6 ft from the tank received 110 rem, another approximately 9 ft away received about 43 rem, and the final worker about 26 ft away received about 19 rem.

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7.4 CRITICALITY ALARMS AND NUCLEAR ACCIDENT DOSIMETRY

Requirements for criticality alarm systems and nuclear accident dosimetry are presented in this section. Criticality alarm systems provide rapid warning to individuals in the immediate accident location and nearby locations to evacuate to a predesignated assembly location. Specifications for the criticality alarm system are found in DOE Order 420.1C (DOE, 2012b) and ANSI/ANS-8.3 (ANSI, 1997c). Key requirements that may be of interest for the health physics staff are summarized in Section 7.4.1. Paxton (1966) noted that lives have been saved in past criticality accidents by radiation alarms coupled with effective evacuation procedures. Nuclear accident dosimetry, discussed in Section 7.4.2, provides the means of determining the dose to workers in the vicinity of the excursion.

7.4.1 Criticality Alarm System

The nuclear criticality safety program evaluation and documentation should include an assessment of the need for criticality accident detection devices and alarm systems, and installation of such equipment where total risk to personnel will be reduced.

Per the criticality safety program, the basic elements and control parameters of programs for nuclear criticality safety shall satisfy the requirements of the applicable American Nuclear Society's ANSI/ANS nuclear criticality safety standards:

As specified in ANSI/ANS-8.3, the need for criticality alarm systems shall be evaluated for all activities in which the inventory of fissionable material in individual unrelated work areas exceeds 700 g of ^{235}U, 520 g of ^{233}U, 450 g of ^{239}Pu, or 450 g of any combination of these three isotopes.

ANSI/ANS-8.3 provides several additional requirements regarding criticality alarm systems. The alarm signal shall be for immediate evacuation purposes only and of sufficient volume and coverage to be heard in all areas that are to be evacuated. Information on sound levels of the alarm can be found in ANSI/ANS-8.3. The alarm trip point shall be set low enough to detect the minimum accident of concern. The minimum accident of concern may be assumed to deliver the equivalent of an absorbed dose in free air of 20 rad at a distance of 2 m from the reacting material within 60 sec. The alarm signal shall activate promptly (i.e., within 0.5 sec) when the dose rate at the detectors equals or exceeds a value equivalent to 20 rad/min at 2 m from the reacting material. A visible or audible warning signal shall be provided at a normally occupied location to indicate system malfunction or loss of primary power. Each alarm system should be tested at least once every three months. An evacuation drill shall be conducted at least annually.

Criticality alarm systems may consist of one to several detectors per unit. In multi-detector units (e.g., three detectors), at least two detectors shall be at the alarm level before initiating the alarm; in redundant systems, failure of any single channel shall be into the trip state (ANSI, 1997c).

7.4.2 Nuclear Accident Dosimetry

Nuclear criticality safety program evaluation and documentation should include:

Assessment of the need for criticality accident detection devices and installation of such equipment where total risk to personnel will be reduced.

Per the criticality safety program, nuclear accident dosimetry is required when the fissionable material mass exceeds the ANSI/ANS-8.3 limits discussed in Section 7.4.1 and the probability of criticality is greater than 10^{-6} per year.

Requirements for nuclear accident dosimetry programs at DOE facilities are found in 10 CFR 835.1304 (DOE, 2011). A nuclear accident dosimetry program shall include the following:

-- A method to conduct initial screening of personnel involved in a nuclear accident to determine whether significant exposures to radiation occurred;

-- methods and equipment for analysis of biological materials;

-- a system of fixed nuclear accident dosimeter units (sometimes referred to as area dosimeters); and

-- personnel nuclear accident dosimeters (PNADs) worn by all individuals who enter locations with specified quantities of fissile material.

Additional desirable features of a nuclear accident dosimetry program include:

-- Facilities to evaluate fixed dosimeters and/or PNADs;

-- a method to determine the approximate neutron spectrum;

-- a method to determine the activity of ^{24}Na in blood and ^{32}P in hair, such as a calibration coefficient determination for a common site survey instruments (such as a pancake GM or a NaI scalar counter) to count in an individual's armpit or other similar gross assay estimation techniques; and

-- a method to correct dosimeter results for actual spectrum (if known).

7.4.2.1 Initial Screening Evaluation

A nuclear accident dosimetry program should provide absorbed dose information within 24 hours after the incident. A nuclear accident dosimetry program shall include a method to conduct initial screening of personnel involved in a nuclear accident to determine whether significant exposures to radiation have occurred (10 CFR 835.1304)[also see ANSI N13.3 (ANSI, 1969)]. Discussions on initial screening evaluations to segregate exposed from unexposed individuals (sometimes referred to as "quick sort techniques") are found in several references (Moe, 1988;

Delafield, 1988; Petersen and Langham, 1966; Hankins, 1979; Swaja and Oyan, 1987).

A common initial screening method is to provide all workers in areas requiring nuclear accident dosimetry with an indium foil in their personnel dosimeter or security badge. During a criticality excursion the foil will become activated by neutrons per the ^{115}In (n, gamma) ^{116m}In reaction and can be measured with a portable beta-gamma survey instrument or ion chamber. The ^{116m}In has a 54-min half-life and releases a 1-MeV beta (maximum energy) and a 1.3-MeV gamma (80% of the time).

An alternate screening is to measure body activity due to neutron activation of the sodium in the blood via the ^{23}Na (n, gamma) ^{24}Na reaction. Sodium-24 has 15-hour half-life and releases a 1.4-MeV beta (maximum energy) and two gammas (1.37 MeV and 2.75 MeV). A beta-gamma survey meter is used to measure the ^{24}Na activity in the blood by placing the detector probe against the individual's abdomen and having the individual bend forward to enclose the detector (Moe, 1988). Alternatively, the probe can be positioned under the armpit with the open window facing the chest area. Moe (1988) noted that this method is less sensitive than the use of indium foils and even a small reading can indicate a significant exposure. An approximate equation to calculate worker dose (D) based on body weight and instrument reading is shown in Equation 7.1:

$$D\,(\text{Gy}) = \frac{80\,(\text{instrument reading in mR / h})}{\text{Body weight (lb)}} \qquad (7.1)$$

Differences in incident neutron energy spectrum, orientation, and measurement techniques relative to conditions used to develop activity-dose correlations can cause significant errors in estimated radiation dose based on quick-sort surveys. Swaja and Oyan (1987) showed that radiation doses estimated from induced body activity can vary by a factor of about 2 due to neutron energy spectrum or orientation effects and by as much as 30% due to probe position. Doses based on indium foil activity can vary by a factor of about 9 due to neutron energy spectrum effects, a factor of 3 depending on foil orientation relative to the incident field, and a factor of about 2 due to probe window setting. Swaja and Oyan (1987) recommended that those count rates above background during quick-sort techniques should be initially interpreted only as an indication that the person has been exposed.

7.4.2.2 Fixed and Personnel Nuclear Accident Dosimeters

A comprehensive nuclear criticality dosimetry system should consist of stationary (fixed-location, area) dosimeters, neutron and gamma dosimeters worn by personnel (i.e., PNADs), and specialized laboratory equipment to evaluate the dosimeters.

Fixed nuclear accident dosimeter units should be capable of determining neutron doses in the range of 10 rad to 10,000 rad with an accuracy of ±25%. They should also be capable of providing the approximate neutron

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spectrum to permit the conversion of rad to rem. The gamma-measuring component of the dosimeter should be capable of measuring doses in the range of 10 rem to 10,000 rem in the presence of neutrons with an accuracy of about ±20%. The number of fixed dosimeter units needed and their placement will depend on the nature of the operation, structural design of the facility, and accessibility of areas to personnel. Generally, dosimeters should be placed such that there is as little intervening shielding and as few obstructions as possible (ANSI, 1969). The number and placement of dosimeters should be periodically reverified to reflect changes in building design and operations. Ease of dosimeter recovery after a criticality event should be considered in their placement, including the possible need for remote retrieval.

10 CFR 835.1304 requires that PNADs be worn by all individuals who enter a controlled area with specified quantities of fissile material. The PNADs should be capable of determining gamma dose from 10 rad to 1000 rad with an accuracy of ±20% and neutron dose from 1 rad to 1000 rad with an accuracy of ±30% without dependence upon fixed-unit data.

ANSI N13.3 (ANSI, 1969) provides general criteria for nuclear accident dosimeters that are reviewed below. Dosimeters, both fixed and personnel, should be protected against radioactive contamination to avoid false measurements. Periodic inventory methods should be established and audits made to ensure that the dosimeters are not removed or relocated without appropriate approvals. Techniques for estimating the effect of body orientation at the time of the exposure should also be developed.

Neutron-Measuring Component of Dosimeter. Criticality accidents create a wide range of neutron energies. Since the neutron dose per unit fluence is strongly dependent on neutron energy, knowledge of the neutron energy spectrum is important in accident dosimetry. In criticality accidents, neutrons with energies greater than about 100 keV contribute most of the dose; therefore, measurement of the fast neutron dose is of most importance. See Delafield (1988) for a review of the different types of neutron dosimeters available for accidents.

Gamma-Measuring Component of Dosimeter. Delafield (1988) noted that the ratio of the gamma rays to neutron dose will vary according to the type of critical assembly and whether or not additional shielding is present. For unshielded assemblies, the gamma-to-neutron ratio can range from 0.1 for a small heavy metal system up to about 3 for a small hydrogen-moderated solution system. A concrete or hydrogenous shielding material will increase the gamma-to-neutron ratio. Gamma dose can be determined by TLD, film, or radiophotoluminescent glass.

Dosimeter Comparison Studies. Sims and Dickson (1979) and Sims (1989) present a summary of nuclear accident dosimetry intercomparison studies performed at the Oak Ridge National Laboratory Health Physics Research Reactor. A summary (Sims, 1989) showed that of the 22 studies conducted over 21 years, 68% of the neutron dosimeter results were within the ±25% accuracy standard and 52% of the gamma dosimeter results were within the ±20% accuracy standard. Most measurements that failed to meet the accuracy standards overestimated the actual dose. Some of their other findings include the following:

-- Doses from hard neutron energy spectra are more accurately measured than those from soft energy spectra

-- The threshold detector unit is the most accurate type of nuclear Accident neutron dosimeter; however, its use is declining due to increasingly strict control of small quantities of fissionable materials

-- Activation foils (ACT) are the most popular nuclear accident neutron dosimeter

-- For gamma dosimeters, TLDs are the most popular and the least accurate, and film is the least popular and the most accurate.

7.4.2.3 Biological Indicators

Earlier in this section, a quick-sort method was described using neutron activation of sodium in the blood as an indicator of worker exposure. More sophisticated laboratory analysis of blood samples can be performed to obtain a more accurate estimate of worker dose, as discussed in Delafield (1988) and Hankins (1979). The use of neutron activation of sulfur in hair ($^{32}S(n, p)^{32}P$) is another method to estimate absorbed dose for workers involved in a criticality accident (Petersen and Langham, 1966). The orientation of the subject can also be determined by taking samples of hair from the front and back of the person. Hankins (1979) described a technique for determining neutron dose to within ±20-30% using a combination of blood and hair activations. Their evaluation was independent of the worker's orientation, of shielding provided by wall and equipment, and of neutron leakage spectra.

7.5 RESPONSIBILITIES OF HEALTH PHYSICS STAFF

The health physics staff should have a basic understanding of program structure, engineering criteria, and administrative controls as related to nuclear criticality safety as reviewed in earlier sections of this chapter. Additionally, the health physicist's responsibilities include emergency instrumentation and emergency response actions.

7.5.1 Routine Operations

During routine operations the health physics staff's responsibilities related to nuclear criticality safety include calibrating, repairing, and maintaining the neutron criticality alarm detectors and nuclear accident dosimeters, and maintaining appropriate records. The health physics staff should be knowledgeable of criticality alarm systems, including alarm design parameters, types of detectors, detector area coverage, alarm set-points, and basic control design. The staff should also be familiar with plans for emergency response.

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The health physics staff should maintain an adequate monitoring capability for a nuclear criticality accident. In addition to the criticality alarm systems and the fixed nuclear accident dosimeters discussed above, remotely operated high-range gamma instruments, personal alarming dosimeters for engineering response/rescue teams, neutron-monitoring instrumentation (in case of a sustained low-power critical reaction), and an air-sampling capability for fission gases should be maintained.

Other support activities may include assisting the nuclear criticality safety engineer or operations staff in performing radiation surveys to identify residual fissionable materials remaining in process system or ventilation ducts.

7.5.2 Emergency Response Actions

The priorities of line management (which could include involving the health physics staff) during a criticality event should be to rescue personnel, prevent further incidents or exposures, and quickly determine those who have been seriously exposed (Moe, 1988). To support these emergency response actions, the health physics staff should be trained in facility emergency procedures. These emergency procedures include evacuation routes, personnel assembly areas, personnel accountability, care and treatment of injured and exposed persons, a means for immediate identification of exposed individuals, instrumentation for determining the radiation levels at the assembly area, and the re-entry and formation of response teams.

Emergency response procedures for conducting the initial quick sort of workers should specify measurement techniques and require that surveyors record methods and instrument settings used for quick-sort operations to ensure proper interpretation of the results. Field results should be compared to pre-established activity-dose relationships developed as part of emergency response procedures to determine if a worker was exposed. Other indicators such as a discharged self-reading dosimeter could also be an indication of a possible exposure.

As an immediate follow-up action for workers identified as being exposed during a quicksort procedure, a more accurate dose estimate should be made using PNADs, fixed-location accident dosimeters, or biological activity analyses (^{24}Na in the blood or ^{32}P in the hair). Part of these more accurate analyses should include: 1) better definition of source characteristics, 2) location of moderating materials, and 3) location and orientation of the person(s) at the time of exposure and action of the person following the irradiation. The health physics staff can provide valuable information to support this analysis, particularly regarding the location and orientation of workers to the excursion if they are involved in the rescue and initial monitoring procedures.

Health physics staff will be responsible for retrieving fixed nuclear accident dosimeters and ensuring that PNADs from any exposed workers are submitted for analysis.

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7.5.3 Special Considerations During Decommissioning Activities

Before decommissioning or disposal of any facilities or equipment, an evaluation should be performed to assess the potential holdup of fissionable material in any equipment. These types of measurements may require the assistance of health physics staff.

Some strippable coatings and surface fixing films are good neutron moderators. Nuclear criticality safety specialists should be consulted when using these coatings to decontaminate surfaces because criticality could be a concern, depending on the geometry of the removed coating when in the disposal unit.

7.6 DEPARTMENT OF ENERGY PLUTONIUM VULNERABILITY ANALYSIS STUDY

In March 1994, Department of Energy Secretary Hazel R. O'Leary commissioned a comprehensive assessment to identify and prioritize the environment, safety and health vulnerabilities that arise from the storage of plutonium in the DOE facilities and determine which are the most dangerous and urgent. The following, provided for historic perspective, summarizes the results of that study.

Vulnerabilities identified included degradation in plutonium materials and packaging, and weakness in facilities and administrative controls that can expose workers and public, or contaminate the environment. The summary of the results presented in this section is taken from DOE/DP-0123T, Assessment of Plutonium Storage Safety Issues at Department of Energy Facilities (DOE, 1994a).

The assessment was commissioned because of recent ruptures of stored plutonium packages and the need to store safely the large amount of plutonium-bearing materials held by the DOE in its aging facilities. The ultimate goal of the assessment was to facilitate safe and stable interim storage until its final disposition, which is not expected to take place for at least 10 to 20 years. The assessment covered 166 facilities at 35 sites and employed a Working Group process. The Plutonium Working Group combined the talent of DOE federal staff, site management and operations contractors, consultants and stakeholders. The Working Group developed plans and technical approaches for the assessment and evaluated the assessment results. Overall, this assessment took more than six months and 80,000 person-hours.

During the assessment, the DOE discussed information about vulnerabilities with stakeholders. About 45 stakeholder groups were involved in either the Working Group meetings or local activities associated with site assessments.

Excluding the classified mass of plutonium contained in nuclear weapon pits at the Pantex Plant in Texas, these sites held 26 metric tons of plutonium. Most of this was located in Rocky Flats, Colorado; Hanford, Washington; Argonne-West, Idaho; Los Alamos, New Mexico; and Savannah River Site, South Carolina. The report detailed the most significant vulnerabilities within each site and across all sites. The Working Group categorized and classified vulnerabilities based on possible effects on workers, the public or environment.

The DOE-wide assessment identified 299 environment, safety and health vulnerabilities at 13 sites, consisting of 91 material/packaging vulnerabilities, 140 facility condition vulnerabilities and 68 institutional vulnerabilities.

In general, the vulnerabilities identified in this assessment posed the greatest hazards to workers. Packaging, which the Working Group found to be widely deficient for long term storage, was often the only barrier that separates the workers from the plutonium. Plutonium solutions were the form most difficult to store and present unique hazards. Plutonium scrap and residue forms are reactive, and some are corrosive enough to degrade containers. Plutonium metals and oxides generally present fewer problems, but much of this material is stored in plastic, which can react with plutonium and cause container failure.

Facility conditions that cause vulnerabilities include aging safety systems, holdup of plutonium in process systems, and design problems that weaken the ability to mitigate accidents like fires or earthquakes. In addition to their impact on workers, such large-scale events have the potential to release plutonium that could affect the public and environment. Institutional vulnerabilities involve incomplete safety analyses, loss of experienced staff, and operational problems such as a backlog of maintenance items on systems that are important to safety.

The assessment found Rocky Flats Buildings 771 and 776 were the most vulnerable facilities, based on combinations of their vulnerabilities and amount of plutonium they hold. These buildings were more than 35 years old and had design deficiencies. The next group of most vulnerable facilities were the Savannah River Site's Building 235-F, FB-Line and Old HB-Line; Hanford's Plutonium Finishing Plant; and Rocky Flats Building 779, 707, and 371. The material in these facilities included plutonium solutions and reactive materials.

This assessment provided the information base to improve the Department's plan for safely managing the future disposition of its plutonium. While most vulnerabilities were already known, this assessment improved DOE's understanding of the issues. It has also enabled the Department to document vulnerabilities, identify new ones and set priorities which will establish a systematic approach to corrective action. DOE began formulating corrective action plans to achieve safe and stable interim storage in September 1994.

The assessment reached several conclusions. Plutonium package failures and facility degradation will increase in the future unless problems are addressed in an aggressive manner. The Department needs a strong, centrally coordinated program to achieve safe interim storage of plutonium. Priority shall be given to plutonium solutions, chemically reactive scrap/residues and packaging with plastics or other organic compounds. Much of the Department's plutonium inventory, including plutonium in holdup, shall be better characterized and site-specific programs shall be implemented to establish package design lives. Management priorities at some site should be reassessed to provide proper attention to those facilities identified as most vulnerable by this assessment. Sites shall evaluate institutional vulnerabilities such as the loss of qualified staff, and compensate for them. Standards or guidelines for packaging, storage and surveillance of plutonium scrap/residues and solutions shall be developed and implemented.

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8.0 WASTE MANAGEMENT

A material is a waste once there is no identified use or recycle value for it. Normally, wastes are considered by their physical form as either solids, liquids, or gasses, except that containerized liquids are considered solid waste under some of the current regulations. Although these forms are each processed differently, there are interrelationships. For example, it may be possible to reduce solid waste by replacing disposable protective clothing with reusable clothing that shall be laundered. The laundry will produce liquid waste. In treating liquid waste, solids may be generated, for example, filters or ion exchange resins. By careful engineering, waste generation, and treatment alternatives, a site can minimize the total waste volume and elect to generate types of waste that can be disposed of. The following sections address potentially contaminated waste and waste terminology and handling of airborne waste, solid waste, and liquid waste. The treatment of excess materials to reclaim plutonium is not a waste treatment process and is not discussed here. Refer to DOE O 435.1. Ch. 1, Radioactive Waste Management, for requirements to ensure that radioactive waste is managed in a manner that is protective of worker and public health and safety, and the environment (DOE, 1999).

8.1 POTENTIALLY CONTAMINATED WASTES

This section discusses the generation, processing, storage, and disposal of wastes in plutonium facilities. It is divided by waste types, treatability groups, and waste disposal.

8.1.1 Waste Types

In addition to the classification of waste by physical form, regulatory definitions determine how waste can be disposed. The Secretary of Energy Notice 37-92, “Waste Minimization Crosscut Plan Implementation” (SEN, 1992), requires annual reports of waste generation by type, waste stream, site, and program. The waste classifications used in the DOE Annual Reports are defined in Table 8.1.

A plutonium facility may generate any of these types of waste, except that high-level waste (HLW) will be generated only from irradiated reactor fuel. Any waste containing at least 100 nCi/g of transuranics (TRU), including plutonium, will be classified as TRU or TRU mixed waste. Waste containing detectable quantities of radioactive materials but less than 100 nCi/g of transuranics will be low-level waste (LLW).

The distinction between sanitary waste and very low-level radioactive waste can be technically a difficult one. Sometimes, material is designated LLW waste because the conditions of use could have resulted in contamination that would be difficult to detect. Techniques and limitations for doing this are discussed below with reference to solid waste.

	Table 8.1. Waste Types[a]
HLW	High-level waste (HLW) is the material that remains following the reprocessing of spent nuclear fuel and irradiated targets from reactors. The HLW is highly radioactive and generates heat on its own. Some of its elements will remain radioactive for thousands of years. Because of this, HLW shall be managed very carefully and all handling shall be performed from behind heavy protective shielding.
LLW	Low-level waste (LLW) is any radioactive waste that is not HLW, spent nuclear fuel, TRU waste, or uranium mill tailings. The LLW is typically contaminated with small amounts of radioactivity dispensed in large amounts of material. The LLW is generated in every process involving radioactive materials in the DOE including decontamination and decommissioning projects.
MW	Mixed waste (MW) is waste that contains both radioactive and hazardous wastes. Any of the types of radioactive waste described can be a mixed waste if it contains any hazardous wastes. In fact, all of DOE's HLW is mixed waste because of the chemicals used to reprocess the fuel that resulted in the generation of the material or because it is suspected to contain hazardous materials.
TRU	Transuranic (TRU) waste refers to waste materials containing elements with atomic numbers greater than 92. These elements are generally alpha-emitting radionuclides that decay slowly. The TRU waste contains a concentration of these elements greater than 100 nCi/g. The TRU waste is not as intensely radioactive as HLW. The TRU waste also decays slowly, requiring long-term isolation.
Sanitary Waste	Sanitary waste is waste that is neither hazardous nor radioactive.
Hazardous Waste	Because of its quantity, concentration, and physical, chemical, or infectious characteristics, hazardous waste may cause or significantly contribute to an increase in mortality, or an increase in serious irreversible or incapacitating reversible illness; it may pose a potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed.

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Table 8.1. Waste Types[(a)] (continued)	
RCRA (USC, 1976a) Regulated Waste	Solid waste, not specifically excluded from regulation under 40 CFR 261.4 (EPA, 2018d), or delisted by petition, that is, either a listed hazardous waste (see 40 CFR 261.30 - 261.33) or waste exhibiting hazardous characteristics.
State Regulated Waste	Any other hazardous waste not specifically regulated under TSCA or RCRA, which may be regulated by a State of Local authority. An example of such waste is used oil.
TSCA (USC, 1976b) Regulated Waste	Hazardous chemical wastes, both liquid and solid, containing more than 50 parts per million of polychlorinated byphenyls.
(a) Definitions from DOE/S-0101, *U.S. DOE Annual Report on Waste Generation and Waste Minimization Progress, 1991-1992*, February 1994 (DOE, 1994c).	

8.1.2 Treatability Groups

In addition to being classified by type, as discussed above, wastes are classified by treatability group, depending on the treatment the waste receives. The common treatability groups are defined in Table 8.2. These are reported in each site's annual waste management report.

Table 8.2. Treatability Groups
LLW
Contact-handled LLW: exposure rate of 200 mR/h or less on contact Remote-handled LLW: exposure rate greater than 200 mR/h on contact
TRU
Contact-handled TRU: exposure rate of 200 mR/h or less on contact Remote-handled TRU: exposure rate greater than 200 mR/h on contact
Mixed Waste (Mixed LLW and Mixed TRU)
Treatable mixed waste has an existing treatment that will eliminate or encapsulate the hazardous constituents of the mixed waste, rendering it LLW or TRU. Treatable includes treatment of mixed waste that results in volume reduction. Non-treatable: no treatment exists

Plutonium facilities generate mostly contact-handled TRU waste (even though they may do much of the handling and processing within glove boxes for contamination control). The most common treatment will be compaction although some facilities have incinerators available.

Depending on the treatment methods available, waste streams may be tailored to be amenable to treatment. Some facilities are able to incinerate TRU waste. Facilities with this capability may need to eliminate halogenated, nitrogenated, or sulfur-containing materials to maximize incinerator acceptance and minimize hazardous effluents from the incinerator.

8.1.3 Waste Disposal

Waste classifications and treatability groups are important because they determine waste disposal options. Sites needing to characterize Pu waste for ultimate disposal at the Waste Isolation Pilot Plant (WIPP) at Carlsbad, New Mexico should do so as that waste is generated. It is generally more expensive to characterize the waste after the fact to meet the WIPP's waste acceptance criteria.

Sanitary waste is by far the least costly and easiest to dispose of. Liquid sanitary waste is disposed of in sanitary sewerage systems or septic systems. Sanitary solid waste is nearly always disposed of by landfill disposal or by incineration with landfill disposal of ash. Because sanitary waste disposal facilities still face various siting and permitting requirements, it is desirable to minimize waste volumes.

Hazardous waste is second in ease of disposal for most DOE facilities. Hazardous waste can be treated to eliminate the hazard only if a permit for the particular waste stream has been granted by the EPA. Hazardous waste treatments permitted in DOE facilities are usually limited to pH adjustment, precipitation, and ion exchange for liquid waste and compaction or incineration for solid waste. Combustible liquids may be incinerated either onsite or offsite, as conditions permit.

Low-level waste is still disposable at most sites. For NRC and state-licensed facilities, commercial disposal is an option, but subject to the requirements of the Low-Level Waste Policy Amendments Act (USC, 1985), which requires individual states or groups of states, called compacts, to develop local disposal facilities. In general, local facilities have not been developed, so disposal volumes are severely limited and/or significant surcharges are imposed in addition to the already high disposal cost.

Several DOE sites are currently permitted to dispose of their own low-level waste by burial. Other DOE sites have long-term storage facilities. In some cases, DOE waste is being placed in retrievable storage in the hopes that the classification of the facility can be changed and the waste allowed to remain permanently.

Mixed waste disposal facilities require all of the permitting for radioactive waste disposal facilities plus all of the permitting for hazardous waste disposal facilities. For this reason, there are very few such facilities in operation, and in general they are rather restricted in the type of waste they can accept. If possible, it is generally better to treat the waste than to destroy or chemically alter the hazardous component. In some cases, mixed waste may be treated to encapsulate the hazardous component so that it no longer has the leachability or other characteristics that cause it to exhibit hazardous properties. Mixed waste requires special permits for treatment, so it is generally preferable to avoid generating it or to treat it in connection with some other process while it is a useful material (before it becomes a waste). For example, if the hazardous component is a metal with some recycle value, or it there are recycle metals in the material, it may be best to alter the process to plate or precipitate the material as a final step in the process line, before it is declared a waste.

Most plutonium facilities will produce TRU waste or TRU mixed waste. According to national policy, DOE TRU waste is supposed to be permanently disposed of at WIPP. Volume allocations have been given to each DOE site for the waste to be placed there, so limiting the quantity of high-level TRU waste is extremely important.

Therefore, volume reduction of TRU waste is highly desirable. Incineration offers the greatest volume reduction and has the added advantage of destroying some types of hazardous constituents (flammable and other organic compounds).

High-level wastes are slated to be disposed of at a high-level waste repository. In the interim, TRU waste is being stored either at the sites that are generating it or, for some DOE facilities, at the Nevada National Security Site, until a final repository is available. Long-term maintenance of interim storage facilities and the prospect of later moves to the final disposal site and burial at that site make high-level waste very costly.

8.2 AIRBORNE WASTE

The only airborne plutonium likely to arise from either normal operations or decommissioning of DOE facilities will be in a particulate form. Although plutonium vapors are possible during cutting and perhaps some grinding operations, they will soon condense to particulate material.

8.2.1 Design Objectives

Plutonium particulates are notoriously difficult to confine and extensive use is made of glove boxes, local ventilation systems, fixatives, and other means to minimize generation of particulates and to confine them. The high-efficiency particulate air (HEPA) filter is the backbone of plutonium air-cleaning systems. Such filters are certified to have a 99.97% removal efficiency for particulates of 0.3 μm and larger and are normally used with at least two in series.

Because confinement systems are subject to component failures and other accidents, differential air pressures are normally maintained so that a breach of containment will not affect occupied areas or the environment. Glove-box lines are at the lowest pressure, plutonium laboratories at a higher pressure, and other occupied areas at the highest pressure but still negative with respect to the outside.

Because plutonium air-cleaning systems are usually expensive to service (requiring workers to be dressed in multiple layers of protective clothing and respiratory protection), and plutonium waste is expensive to dispose of, measures are taken to protect the life of plutonium air-cleaning systems. Extraneous particulates are eliminated by HEPA filtration of incoming air. (These HEPA filters may be disposed of as sanitary waste.) Roughing pre-filters are used to capture the bulk of particulates and prolong the life of HEPA filters.

Care shall be taken in designing HEPA filter installations for plutonium facilities so that provisions are made to safely change the filters while maintaining contamination control. Such measures normally include redundant banks of filters (in parallel) that can be valved-out for filter change, location of HEPA filter banks in enclosed rooms that are themselves HEPA-filtered, and appropriate provisions for filter bag-out.

New filters shall be tested after they are installed to ensure proper gasketing, etc. Once in place, they shall be periodically retested to ensure that HEPA efficiency is maintained. For this reason, HEPA filter installations shall have ports for the introduction of a challenge aerosol upstream of the filter and collection of a representative sample in a region of laminar flow downstream of the filter. The HEPA filters in plutonium use sometimes fail from mechanical fatigue and vibration rather than plugging or being subject to some other mechanical failure. Further discussion of HEPA filters and filtration systems is available in DOE Order 420.1, *Facility Safety* (current revision, (DOE, 2012b)), DOE Guide 420.1, *Safety Design Guide for use with DOE O 420.1* (current revision, (DOE, 2012a)), DOE-STD-3020-2015, *Specification for HEPA Filters Used by DOE Contractors*, (DOE, 2015), and DOE-STD-3025-2007, *Quality Assurance Inspection and Testing of HEPA Filters* (DOE, 2007a).

In addition to the above features of the air-handling system, there may be process-selection features that will minimize the generation of airborne plutonium. If at all possible, plutonium compounds should be handled in sealed containers or, in the case of a metallic solid, the material encapsulated. Wet mechanical processes, such as cutting and grinding, usually generate fewer particulates than dry ones, so they are often preferred. However, it is also important to minimize the use of chemicals that will attack the air-cleaning system or contaminate the filters with hazardous chemicals, making them mixed waste. Even moisture will shorten the life of HEPA filters, so wet processes should be enclosed to the extent practicable and demisters and/or heaters used to pretreat the air from wet processes prior to HEPA filtration.

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The final consideration in the design of air cleaning systems for plutonium operations is the probability and consequences of accidents. In general, plutonium air-handling systems are designed so that all probable accidents, including the failure of a single HEPA filter, do not have measurable consequences offsite. It will be necessary to design the system for all probable meteorological conditions, including (for some regions of the country) tornados. The system shall also be designed so that some improbable (but not impossible) events (accidents) have consequences that are less than catastrophic. For example, the simultaneous failure of two HEPA filters in series is highly unlikely (without a common cause such as high differential pressure from an explosion or meteorological event) but facilities shall be designed so that these events are not likely to cause fatalities offsite. The minimum performance criteria for the air-cleaning systems are dictated by DOE design criteria. Other design parameters are finalized during the Environmental Impact and Safety Analysis processes. They will differ from facility to facility.

8.2.2 Operational Controls

Plutonium air-handling systems shall be operated within the design safety envelope of the system. Beyond that, there are measures that can further reduce the potential for airborne plutonium, even in glovebox operations. Even within glove boxes, plutonium should be containerized, preferably doubly encapsulated whenever possible. Spills should be cleaned up promptly. If rags or tissues are contaminated, they should be bagged as soon as possible.

8.2.3 Waste Treatments

The principal treatment for cleaning plutonium from air is HEPA filtration. There are other technologies that can be used for pretreatment, but the most common is filtration. Electrostatic precipitation, wet scrubbing, demisters to remove moisture, and other technologies may have specific applications. (Treatment of the HEPA filters, a solid waste, and the wet scrubber effluent, a liquid waste, are discussed in Sections 8.3 and 8.4, respectively.)

8.2.4 Sampling and Monitoring

Sampling is the primary method used to achieve a complete and accurate legal record of releases after they have occurred. The primary requirement for a particulate air sample of any type is that it be representative of the stream being measured. This translates into isokinetic sampling in a laminar flow section of the exhaust duct. The parameters needed to achieve such a sample are given in numerous references such as Chapter 10 of Implementation Guide G 441.1-1C, Ch. 1(DOE, 2011a). For sampling, the analytical methods are the same as those discussed in Chapter 3 of this document for workplace sampling.

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Monitoring is used to determine if current conditions are within expected parameters and to initiate corrective action if they are not. For monitoring, the system design should conform to ANSI N42.18, Specification and Performance of On-site Instrumentation for Continuously Monitoring of Radionuclides in Effluents (ANSI, 2004). The choice of the filter medium will depend on the analysis that will be done on the sample. For samples containing only plutonium particulate, a non-absorbing filter such as a membrane filter will have the highest efficiency for alpha counting. In all cases, the final count shall be done after any residual radon has decayed because it will often result in a large amount of alpha on the filter that is not plutonium. If there are other radionuclides in the waste stream that cannot be decayed in a reasonable time, either alpha spectroscopy or chemical separation shall be done. Chemical analysis shall also be done if there are stable contaminants of interest such as beryllium or heavy metals. The nature of these procedures is beyond the scope of this document.

8.2.5 Disposal

Airborne effluents are not stored. Disposal of the airborne effluent, possibly containing traces of plutonium, is generally arranged by the design of the facility and the existing air quality permits. Normally, the design of the facility is such that the method of disposal of the cleaned effluent should be unimportant during normal operation. However, the facilities are designed to minimize the impact of a filter failure or operational difficulty that results in a release. Disposal of airborne effluents is handled at the design, environmental impact assessment, and safety analysis stages of facility construction. Disposal of secondary waste from air cleaning is covered in the sections that follow.

8.3 SOLID WASTE

Solid waste will come from all phases of operation and from decommissioning of plutonium facilities. Because most plutonium solid waste will be TRU (containing more than 100 nCi/g), containerization of the waste will be done in anticipation for transportation to the WIPP, which is an expensive and detailed process. Thus, it is highly desirable to minimize the generation of solid waste in the design, operation, maintenance, and decommissioning of plutonium facilities.

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8.3.1 Design Objectives

One of the principal means of minimizing solid waste is to minimize the area that becomes contaminated by plutonium and to ensure that all surfaces contaminated by plutonium are readily cleanable.

Glove boxes are often used to contain contamination and permit work in minimal protective clothing that can be reused to minimize waste volumes. By assuring that these are in isolated areas that are covered with easily cleanable materials and maintained at negative pressure with respect to the rest of the facility, waste is minimized even during minor accidents.

The choice of surface materials is extremely critical. For example, concrete floors will become impregnated by plutonium particulates or solutions and will require fixatives or scabbing to control contamination. Relatively large quantities of solid waste will be generated when facilities are decommissioned or major modifications are done. Conversely, electropolished stainless steel is easily cleaned, even to releasable levels generating only small quantities of TRU waste.

Choosing components that can be easily maintained rather than totally replaced may also be an effective strategy at minimizing waste. Whenever possible, choose equipment for which high-maintenance components can be located outside of contaminated areas. For example, many mixers, saws, and other such components have been adapted so that the motor is located outside the glove box where it can be maintained or replaced without concern for contamination status, while the working or tool end operates in a contaminated environment.

8.3.2 Operational Controls

Operational controls for waste-management purposes in plutonium facilities serve two distinct purposes: waste volume reduction (waste minimization) and waste classification control. Each of these is discussed briefly below. Operational controls to reduce the probability of accidents or minimize their consequences are also important but are not directly addressed as part of waste management.

8.3.2.1 Waste Minimization

Plutonium facilities should have a waste minimization program. The objective of a waste minimization program is the cost-effective reduction in the generation and disposal of hazardous, radioactive, and mixed waste. The preferred method is to reduce the total volume and/or toxicity of hazardous waste generated at the source, which minimizes the volume and complexity for waste disposal.

The waste minimization program applies to all present and future activities of the facilities that generate hazardous, radioactive, and/or mixed wastes. Furthermore, waste minimization is to be considered for all future programs and projects in the design stages, and should be included in all maintenance and/or construction contracts.

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All managers of facilities or activities that generate hazardous, radioactive, and mixed waste are responsible for:

-- Minimizing the volume and toxicity of all radioactive, hazardous, and radioactive mixed waste generated, to the extent economically practicable

-- preparing and updating waste minimization plans for their waste-generating facilities or activities. Small waste generators in a larger facility may be grouped with others in a facility or activity plan

-- implementing the facility-specific or activity-specific waste minimization plan

-- providing input to the organization responsible for waste characterization and minimization, to support the waste minimization program

-- communicating waste minimization plans to their employees, and ensuring that employees receive appropriate training

-- ensuring that existing system/equipment replacement or modification is designed and installed to minimize generation of waste

-- developing new waste minimization strategies, and identifying cognizant staff for waste minimization communications between facility personnel

-- identifying new waste generating facilities or activities and significant process changes to existing facilities or activities to the waste characterization and waste minimization organization.

Waste volume control, or waste minimization, involves limiting the amount of material that becomes contaminated, segregating clean and contaminated material, and prolonging the useful life of equipment and material to minimize replacement. Sometimes, materials can be completely cleaned so that disposal as sanitary waste (or refurbishment in clean areas) is an option.

Program design decisions can affect TRU waste-generation. For example, the quantity of protective clothing may be a significant factor. If an incinerator is available, combustible protective clothing may be selected to have a low ash content and generate a minimum of harmful effluents such as oxides of nitrogen or halogenated compounds. In other facilities, water-washable, reusable protective clothing may minimize waste disposal.

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In many nuclear facilities, contamination of packaging materials is a problem. For example, if a tool or material (e.g., a pump or some ion exchange resin) is to be used in a contaminated area, as much of the packaging material shall be removed as possible before the material enters the radiological area.

Another opportunity for waste minimization occurs when materials are used as a contingency protection against contamination. For example, strippable coatings may be applied to an area that is not expected to become contaminated or may receive only minor contamination so that it can be easily cleaned. Another example involves the disposition of disposable surgeons' gloves, which are routinely worn inside glove-box gloves. Unless there are serious contamination control problems in the facility, these can be surveyed and disposed of as sanitary waste rather than LLW or TRU waste.

If a piece of equipment is to have more than a single use in a contaminated environment, every possible measure should be taken to ensure its continued reliability rather than relying on frequent replacements. Tools should be of the highest quality and maximum flexibility consistent with the situation. For example, if a wrench is needed to maintain a piece of equipment in a glove-box, consideration should be given to future needs and storage provisions. A socket set with interchangeable sockets may ultimately create less waste than a box-end wrench of each size that is needed.

Likewise, all tools and equipment to be placed in a contaminated environment should be tested for reliability and preferably used on a clean mock-up to ensure their serviceability before they become contaminated. There is often a temptation to put the equipment into the plutonium service when it first arrives rather than test it completely first. This can result in unnecessary waste volume.

8.3.2.2 Waste Classification Control

Many operational controls involve measures to ensure that the waste generated is TRU waste rather than mixed-TRU waste, or that if it is mixed-TRU, it is of a composition that can be treated. Tight controls in the following areas are necessary to minimize mixed waste (and hazardous waste) problems: procurement of hazardous chemicals, actions of subcontractors and vendors, and training of workers. In some cases, decontamination processes have been used that result in mixed waste, such as Freon cleaning, electropolishing, and chemical decontamination. These should be used only after due consideration of the waste management consequences. In some cases, these mixed wastes can be readily treated; in other cases, their use needs to be avoided. Some new techniques are designed specifically for waste minimization and waste classification control. For example, one method involves abrasive blasting with solid carbon dioxide (dry ice), which sublimes after use and can be exhausted through a HEPA filter, leaving no added material to the

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waste. Decontamination with high-pressure water has some similar advantages, but care shall be taken to ensure that used decontamination solutions do not spread contamination.

8.3.3 Waste Treatments

Available treatments for solid waste include compaction and incineration. In specific cases, there may be decontamination options available, as well.

Compaction, with pressures in the range of 40,000 to 60,000 psi, is most often used on paper, fabric, and plastic although it is effective on glass, sheet metal, and some other materials. With such ordinary materials, one commercial reactor has approached up to 800 pounds of waste per 55-gallon drum, although an average of 500 pounds per drum is considered to be very good.

Compaction is done by drum compactor or box compactor. Compacting into a drum or a 4- by 4- by 8-ft box is normally a labor-intensive operation and often involves some risk of personnel exposure, even though the better compactors are equipped with HEPA-filtered ventilation systems. Supercompaction uses considerably higher pressures than compaction, normally 200,000 psi or greater. Supercompaction usually involves compacting filled waste drums into a box or overpack. Supercompaction has been success-fully used on piping and other materials that are normally considered noncompactable.

It is really a choice of words whether incineration is considered a disposal technique or a volume-reduction technique. All carbon, oxygen (except for any that becomes bound in oxide ash), nitrogen, hydrogen, and sulfur present in the incinerator feed will be converted to gasses and disposed to the atmosphere. Plutonium and most metals will remain as a solid material. As a volume-reduction technique, incineration is very successful, with volume-reduction factors up to 200:1 or greater achieved on some waste streams. There have been licensing delays for some incinerators, and often there are limitations brought about by air quality restrictions. There is also the possibility that incinerator ash may be a mixed waste due to the concentration of other impurities such as heavy metals in the waste. If a facility has an incinerator, a quantity of the feed material can be incinerated to determine if the waste will have hazardous characteristics before the material is contaminated. In some cases, it is desirable to size-reduce or repackage in combustible packaging before incineration.

Decontamination is most successful when the material can be recycled for use in a nuclear facility since the need to prove releasability (cleanliness) is eliminated. Nevertheless, cleaning material for unrestricted release is also possible in some cases. It may also be possible to decontaminate an item enough to change its classification from TRU waste to LLW, thereby allowing immediate disposal of the item, while a relatively small quantity of decontamination waste is stored as TRU waste.

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Electropolishing to remove the thinnest metal surface has been very effective and produces a relatively small waste volume, especially when one of the wetted sponge units is used rather than an emersion tank. Surface scabbling has been used in decontamination of concrete, and various abrasive blasting methods have also been effective. Strippable and self-stripping coatings may be used to decontaminate surfaces, even though the primary application of strippable coatings has been in preventing contamination of surfaces.

There are occasionally mixed strategies that work well. Used HEPA filters may be removed from their frame for compaction. Metal frames may be decontaminated and wood frames may be incinerated. Whatever treatment or disposition path is chosen, insure that during waste generation, all waste is characterized, accumulated and packaged in direct readiness for final disposal or reuse.

8.3.4 Sampling and Monitoring

Solid waste is monitored for several reasons: to determine if it can be released as sanitary (or hazardous) waste; to distinguish its classification as either LLW or TRU waste, depending on the concentration of transuranic isotopes; and to obtain defensible values for documenting shipping and disposal quantities. See section 4.2.4.2 for guidance on release surveys.

8.3.5 Storage and Disposal

Solid sanitary waste, hazardous waste, and LLW can normally be disposed of using existing procedures. Transuranic waste, HLW, and most mixed waste may have to be stored for a period of time awaiting approval of disposal facilities; they will have to be stored in a manner that prevents routine and accidental impact on the environment. They shall be protected from unauthorized access, fire, flood, or water damage. Containers shall be protected from corrosion or other deterioration and an accurate inventory of the material shall be kept. Most facilities prefer to store such material in a form that they believe will be shippable. Refer to the WIPP waste acceptance criteria for venting requirements for TRU waste containers.

Existing storage and packaging requirements for plutonium metal and oxide are addressed in DOE Order 460.1D (DOE, 2016d). The DOE's existing storage practices for plutonium and plutonium-containing materials and wastes were evaluated at a DOE Workshop in May 1993 [see Assessment of Plutonium Storage Safety Issues at Department of Energy Facilities (DOE, 1994a)]. The draft recommendations from this workshop for metals and oxides that are not in containment vessels with certified hermetic seals [per ANSI N14.5 (ANSI, 1997a)] are given in Table 8.3. In 2008 DOE published the Nuclear Material Packaging Manual, DOE M 441.1-1 (DOE, 2008e). The manual provides detailed packaging requirements for protecting workers from exposure to nuclear materials stored outside of an approved engineered contamination barrier. The variety of plutonium-containing materials is illustrated by the inventory information for the Hanford Site contained in documents by Christensen et al. (1989) and Hoyt (1993).

8.4 LIQUID WASTE

Liquid waste from plutonium facilities includes various aqueous waste streams such as cooling water, laundry waste, and floor-drain waste, and numerous organic and inorganic chemical wastes. The design criteria and operational controls to make these streams treatable and disposable, and the methods to treat them are beyond the scope of this document and are highly facility-specific. General considerations are given below.

8.4.1 Design Objectives

If a facility process requires the generation of plutonium-contaminated liquids, it is probably best to ensure that the mother liquid is demineralized water and that plutonium is the only contaminant added. In this case, the liquid can be filtered, demineralized, and recycled. Any other chemicals added to the water will complicate treatment, increase the volume of secondary waste, and diminish the opportunity for recycle. Organic contaminants such as oils, solvents, and detergents will likely foul the ion exchange resin, greatly increasing resin volume.

A pure organic solvent has many of the advantages of demineralized water, especially if it does not chemically degrade or evaporate under the conditions of use. (Solvents are not usually amenable to purification by ion exchange; however, filtration, extraction into aqueous solutions, and distillation are possible.) Unfortunately, most organic solvents are classified as hazardous materials and any material that comes in contact with them is likely to be a hazardous (or mixed) waste when it is disposed of. If the solvent is combustible and the facility includes an approved incinerator of sufficient capacity to handle the secondary waste, then the organic solvents are highly desirable.

While such guidance may be helpful in facility design, there will be waste streams that do not conform to either of the situations above. Most decontamination wastes, laundry wastes, and floor-drain wastes are examples. In decontamination, it is important that the process is selected with provisions to manage the waste. In many cases, the nature of the facility determines that the waste will be a mixed waste. In these cases, minimizing the volume is most important. For example, if a plutonium-contaminated surface has been painted with a lead-based paint, the decontamination waste will be mixed waste unless it is further treated to ensure that the lead is not in a leachable form. In this example, removing the paint by dry ice blasting, high-pressure water blasting, heat, or a similar method would be preferable to sand blasting in which the sand would be added to form an additional mixed waste that could require storage for many years.

Laundry wastes are a special problem because radioactive contamination, body oils, and odors shall be removed from protective clothing. For a time, dry cleaning was extremely popular, because the solvents were easily redistilled and recycled. However, because the solvents were usually chloroflorocarbons and because the small volume of waste generated was mixed waste, this method is now rarely used. Incineration of disposable protective clothing is an outstanding choice if an incinerator of sufficient capacity is available, but this is rarely the case. Water washing is often the method of choice. In a few cases, plutonium in the waste stream is removed adequately by filtration and the effluent can be disposed to a sanitary sewer or to the environment under a National Pollutant Discharge

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Elimination System permit. It is important to select a detergent for water washing that does not foul or plug the filter and that has a minimal impact on ion exchange resins if they shall be used. Many household laundry detergents have fillers such as wood fiber to give them greater bulk. These should never be used because the fiber has no beneficial use and will end up as solid waste. As a general rule, extensive testing on clean material should be done to optimize disposal of laundry waste.

Floor-drain wastes are much more of a problem in some facilities than in others. In some facilities, there is a culture that says, “if you don't know what to do with it, pour it down the floor drain.” Such practices can lead to a mixture of water, detergent, oil, antifreeze, and other substances that clog filters and foul ion exchange resins and lead to environmental compliance issues. In the worst cases, solidification with Portland cement is the only alternative, and this increases an already large volume. The use of catch basins under chemical and lubricating systems and extensive training of personnel minimize the probability of such occurrences. Oil skimmers on floor drain collection tanks are sometimes advisable, as well.

8.4.2 Operational Controls

Once the facility is properly designed, training of personnel is the primary operational control against generating excessive volumes of waste or against generating waste with contaminants that interfere with treatment or change the classification.

Some facilities have used color codes to prevent materials from entering an area where they will adversely affect waste management. For example, certain electronic contact cleaners may be banned from some radiologically contaminated plant areas because they would generate mixed waste. The procurement organization might code all such materials red and certain areas would be posted to indicate that the materials were not allowed.

Whatever the system, it is important that each employee be trained to effectively use the system and that well-intentioned housekeeping efforts do not result in excessive waste volumes.

8.4.3 Waste Treatments

The primary treatments for aqueous waste are

- pH adjustment
- precipitation
- liquid-solid separation such as flocculation and filtration
- ion exchange
- distillation
- purification by reverse osmosis
- solidification.

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The primary treatments for organic solvents are:

-- Solvent extraction
-- filtration
-- incineration.

Virtually all of these processes (except pH adjustment) are likely to result in secondary waste that requires treatment and/or disposal. In all cases, recycling of the primary solution is desirable because it reduces monitoring cost and waste-disposal liability and cost. A brief description of the use of each of these treatment methods is given below. Extensive design and engineering should be done before any method is selected in order to ensure meeting design objectives.

8.4.3.1 pH Adjustment

This treatment is used on aqueous systems to meet discharge limitations or to make the solution amenable to other treatment. A mineral acid, such as sulfuric, hydrochloric, or nitric, is normally used to lower the pH. A base, such as sodium, potassium hydroxide, or occasionally ammonia, is used to raise the pH. The solubility of some contaminants will be affected by the pH of the solution. For example, an acidic solution containing iron may show a copious precipitate of ferric hydroxide upon the addition of a base.

8.4.3.2 Precipitation and Co-precipitation

Precipitation and co-precipitation are used to decrease the solubility of some compounds. Precipitation involves making the contaminant into an insoluble material by the adjustment of pH or the addition of a chemical. For example, nickel may be rendered insoluble by the addition of sodium dimethylglyoxime. Co-precipitation is similar but is used when the contaminant is not present in sufficient quantity to form a filterable solid but will incorporate into another precipitate as it forms or will adhere to the surface of another precipitate. In some waste treatment processes, a stable isotope of the radioactive contaminate is added to co-precipitate the radioactive material that is not present in sufficient quantity to form a precipitate on its own. Precipitation is always followed by some liquid/solid separation technique.

8.4.3.3 Liquid-Solid Separation Techniques

Treatments such as flocculation and filtration are used to remove solid and colloidal contaminates either directly from the waste stream or following a precipitation or co-precipitation process. Centrifugation or settling are sometimes used to remove gross quantities of solids preceding some filtration processes. These processes separate the waste into a concentrated and dilute waste stream, both of which will probably require further treatment. The bulk liquid fraction may be subject to filtration before recycling or disposal. The fraction with the high concentration of solids may be subject to evaporation, or drum or filter-press filtration to remove excess water, or it may be solidified as discussed below.

Where the contaminant is present as a colloid or extremely fine particulate, co-precipitation or flocculation may be required before settling, centrifugation, or filtration. Flocculation involves the addition of an extremely small quantity of a long chain molecule that has the appropriate electrostatic affinity for the contaminant present. The flocculent molecules gather the contaminant into rather large particles that are amenable to settling and filtration. The flocculent and dosage (addition ratio) are usually selected by trial and error. Flocculents do not add appreciably to the waste volume and usually do not add a contaminant that results in a mixed waste. Residual flocculent may, however, foul ion exchange resins or reverse osmosis membranes, so it is important that the quantity added be closely controlled.

8.4.3.4 Ion Exchange

Ion exchange is one of the most useful waste treatment techniques. Aqueous wastes that are free of oil and other organics and contain only very minimal quantities of solids may be subject to ion exchange on cation resin, anion resin, or specialty resins, either alone or in combination. If the contaminant is present as a cation, such as sodium, ammonia, or calcium, a cation resin can be used to replace the cation in solution. The cation from the resin will go into the solution to replace the contaminant cation. If the water stream is being recycled, the cation resin will probably be in the hydrogen form so that only hydrogen ions will enter the solution. If a hydrogen form of cation resin is used by itself, the water solution will likely become more acidic (lower pH). If an anion resin is used, anions in solution will be replaced with anions from the resin. Although resin may be in a chloride or other form, the hydroxyl form of the resin is often used so that anions are replaced with hydroxyl anions (-OH). If only a hydroxyl anion resin is used, the solution will drop in pH, becoming more basic. If both a hydrogen form of cation resin and a hydroxyl form of anion resin are used, the ions they add combine to form water, so both resins are used on demineralized water systems that are recycled. One disadvantage of most ion-exchange resins for waste treatment is the fact that they remove all ionic contaminants, not just the radioactive ones, and so are exhausted earlier than they might be. Selective resins are available for a few materials, most notably cesium, but are not available for plutonium.

In some applications, radionuclides pass through both cation and anion resin beds. This is assumed to happen because they are not present in an ionic form. They are either colloidal or are present in a molecule or complex that is neutral. In these cases, pretreatment or multiple treatment steps may be required.

Unfortunately, plutonium may be present as a cation, anion, neutral chemical complex, or colloid. Testing is almost always required to optimize plutonium removal. One additional limitation in the use of most ion exchange media for plutonium and other alpha-emitting radionuclides is that the radiation degrades the resin over time. Organic ion exchange media loaded with large quantities of plutonium may emit hydrogen and

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may become unstable when exposed to oxidizing materials such as nitric acid.

In some applications, ion exchange resins are "recharged" by the addition of large quantities of a particular ion (e.g., hydrochloric acid may be used to reconvert spent cation resin to the hydrogen form). In nuclear applications, this is rarely feasible because of the need to dispose of the recharge solution and because of the large quantity of rinse water used to remove the excess recharge solution from the resin.

8.4.3.5 Distillation

Distillation (including vacuum distillation) is at least conceptually simple. It removes all but volatile contaminants. In practice, some contaminants will cause foaming, and evaporator maintenance is often a problem. If laundry waste or other waste-containing detergents are to be evaporated, it may be necessary to add an antifoaming compound. Although these are sometimes effective, they often degrade with heat faster than the detergents or other compounds causing the foaming. Few evaporators take the product to dryness, as this often creates a scale build-up. If the evaporator bottoms are removed as a solution, they shall be solidified, usually with some increase in volume.

8.4.3.6 Purification by Reverse Osmosis

This process is highly effective on relatively pure water streams. The water is passed through a semipermeable membrane by mechanical pressure, leaving contaminants behind. The result is generally 80% to 99% of the influent water released as pure water, with the remainder containing all of the contaminants. Reverse osmosis has the advantage over ion exchange in that it will remove nonionic contaminants although these often shorten the life of the membrane. It is much more energy-efficient than distillation and requires much less equipment for the same volume of water treated. It is sometimes used as a "polishing" technique to further treat relatively clean water.

8.4.3.7 Solidification

Solidification is often a last-resort treatment because, while the other treatments described reduce the volume of solid waste requiring disposal, solidification increases it. Nevertheless, it is useful for some waste. Portland cement is the most common solidification medium for water solutions, aqueous suspensions, and resins. However, there are other proprietary materials, including some especially for oils and other organic compounds.

8.4.3.8 Solvent Extraction

Solvent extraction is used exclusively with organic solvents and involves mixing the solvent with an immiscible aqueous solution in which the contaminant is soluble. In this way, the contaminant is transferred to the

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aqueous solution for further treatment. (Solvent extraction may also be used in the other mode, in which the contaminant is transferred to the organic solvent solution, but this has fewer applications in waste management.) The organic solution is usually recycled.

8.4.3.9 Incineration

Incineration is an ideal waste-management technique for combustible solvents and other liquids that do not yield toxic or hazardous combustion products. The volume reduction from feed material to ash is usually outstanding. Incinerators are usually equipped with wet scrubbers, demisters, and filters to ensure that the effluent released to the environment is acceptable and ALARA. These features create secondary waste that shall be dealt with appropriately, but the disposal efficiency usually makes them well worthwhile.

8.4.4 Sampling and Monitoring

Sampling and monitoring of liquid waste streams are usually straightforward. Bulk liquid in tanks shall often be mixed, usually with a recirculating pump, before dip sampling to ensure a representative sample. Liquid effluent streams are often sampled with a flow-proportional sampler. For on-line monitoring, a small ion exchange column is used to concentrate ionic contaminants, and a detector is placed on the column for gamma analysis.

8.4.5 Storage and Disposal

Sanitary liquids and those meeting disposal criteria may be released to the environment or to sanitary waste treatment systems (sewerage systems). Hazardous liquid waste may be shipped, with excess absorbent material in compliance with 40 CFR, to a licensed treatment facility. Small quantities of radioactive-contaminated liquids, such as samples, may be shipped in a similar way, but most liquid waste shall be solidified prior to shipment or disposal. It is preferable to store only solid waste, as well. The recommendations of Table 8.3 are applicable to the storage of plutonium-containing liquids as well as solids. In particular, where long-term storage of plutonium solutions may occur, even within glove boxes, it is advisable to avoid plastic containers unless one can be certain that the alpha radiation will not have degraded the container.

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Table 8.3.	Recommendations for Storage of Plutonium Metal and Plutonium Oxide at Department of Energy Facilities
The following recommendations are made to improve current plutonium storage safety practices. Until new equipment and facilities become available to package plutonium based upon long-term standards, these recommendations are applicable to plutonium metal or plutonium oxide stored outside of glovebox lines in containers that do not have certified hermetic seals (i.e., per ANSI N14.5 (ANSI, 1997a)). These should be used in addition to the applicable requirement in DOE M 441.1-1 (DOE, 2008e).	
1.	Plutonium solutions, metal turnings, or particles with specific surface areas greater than 1 cm^2/g should not be stored outside of glove boxes.
2.	All packages containing plutonium metal should be taped, re-taped, and placed in plastic bags prior to handling.
3.	Inspections should incorporate use of adequate personnel protection. Inspection practices should be codified in surveillance plans. These plans should reflect current facility operating status. There shall be personnel radiological surveillance during all handling operations. Personnel protection during operations should include protective clothing and gloves and, if necessary, respiratory protection.
4.	Inspection of containers should be integrated with audits for materials control and accountability (MC&A) to minimize container-handling and attendant radiation exposure to ALARA levels.
5.	Containers should be inspected for abnormalities (e.g., mass change, container deformation, or discoloration) using visual inspection, weighing, or video surveillance where such capability exists. Findings should be recorded for safety and MC&A evaluations. Visual inspections should be made at intervals of 1 week and 1 month after the material's initial containment and annually thereafter.
6.	Packages containing more than 0.5 kg of plutonium metal should undergo an annual surveillance in which the total mass of the package is determined to an accuracy of ±0.5 g and compared with the preceding year's mass and with the initial (reference) mass at the time of packaging. A storage package should be evaluated (e.g., opened and inspected, radiographed) if any of the following conditions are evident:
	a. The outer storage vessel is bulged or distorted. b. Hydride-catalyzed oxidation is suspected. Such reaction is indicated by a mass increase in either of two circumstances:

	Table 8.3 (cont'd)
	i) For packages whose masses continue to increase since initial packaging or for which historical mass data are unavailable (see item 6 above), a mass increase greater than 15 g per kilogram of plutonium over a one-year period indicates a hydride-catalyzed oxidation reaction.[(a)] ii) For a package whose mass has remained constant over a period of several years (less than ±0.5 g change) from its reference value, then undergoes an annual mass increase of more than 2 g per kilogram of plutonium, hydride-catalyzed reaction is indicated. Such a package is particularly suspect. The indications are that a previously sealed container may now be breached and that the continuing reaction may lead to rapid containment failure within 12 to 24 months
	c. The measured package mass, relative to the reference mass, corresponds to the mass that indicates formation of oxide with a volume exceeding 10% of the free volume of the inner vessel. Each 1-g increase in mass corresponds to formation of 1.5 cm^3 of oxide with a density of 50% of the theoretical value of 11.46 g/cm^3.
7.	Inspected containers exhibiting abnormalities (e.g., external contamination, bulging, discoloration, or other anomalies) should be repackaged in accordance with well-defined procedures (see items 3 and 4 above). Handling such containers outside of a glove box or conveyor confinement requires respiratory protection until the package is placed in an overpack container (e.g., taped metal can or sealed plastic bag) before further handling and transport.
8.	As an interim measure, material that is repackaged may be placed in a food pack can or slip-fit (Vollrath) container with a secured lid. If possible, metal should be repackaged in a configuration containing at least one gas-tight seal. No plastic material should be in direct contact with plutonium metal or oxide, and use of plastic in outer layers of packaging should be minimized.
9.	When packaging metal, hazardous or pyrophoric material such as plutonium hydride should be removed. However, it is not necessary to remove protective oxide film. Metal should be packaged in as dry and inert an environment as possible to minimize corrosion (<100 ppm H_20).

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	Table 8.3 (cont'd)
10.	Impure oxide from sources other than metal should be thermally stabilized at 1000±100°C for at least an hour, or placed in a combination of a slightly lower temperature (850°C) for longer heating time to result in the lowest loss on ignition practicable with existing equipment. This ensures complete conversion of substoichiometric material and aids small-particle coalescence, which diminishes dispersal risk.
11.	Because plutonium oxide has greater potential for dispersion in severe accidents, it should have priority over metal for storage in structurally robust vaults. Metal should be characterized to ensure that it has not converted to oxide while in storage. Stored plutonium will have an increasing radiation level because of the build-up of ^{241}Am. Therefore, characterization of metal should be done as soon as possible and should make full use of small-sample statistical methods to minimize worker exposure. The results of characterization should be integrated with a site's surveillance plan, as well.
12.	Quality assurance measures, labeling, and material characterization are essential. Material and storage packaging specifics should be thoroughly documented.

(a) A higher oxidation rate may occur if the contained metal exhibits a high surface-area configuration, such as sheet or foil. The maximum annual increase for normal (uncatalyzed) oxidation of a given metal geometry can be calculated using a reaction rate of 3 x 10^{-7} g oxygen/cm^2-minute measured for alpha-phase plutonium under moist conditions at 50°C.

9.0 EMERGENCY MANAGEMENT

It is DOE policy that all DOE facilities and activities be prepared to respond to operational emergencies in a way that minimizes consequences to workers, the public and the environment. Formal emergency management programs are the final element of DOE's defense-in-depth against adverse consequences resulting from its operations.

9.1 EMERGENCY MANAGEMENT IN DOE

DOE Order 151.1D (DOE, 2016b) requires DOE elements and contractors to plan and prepare for the management of emergencies. The following discussion of emergency management principles, requirements and guidance is generally applicable to DOE plutonium facilities. Specific facility requirements are in accordance with the individual facility DOE contract. The Emergency Management Guides (EMG), DOE G 151.1-1A, DOE G 151.1-2, DOE G 151.1-3, DOE G 151.1-4, provide guidance for implementing DOE Order 151.1C (DOE, 2007d, 2007e, 2007f, 2007g).

9.1.1 Basis for DOE Emergency Management Policy

DOE emergency management policy and direction is based on the following: planning and preparedness commensurate with hazards; integrated planning for health, safety and environmental emergencies; classification of and graded response to emergencies, and; multiple levels (tiers) of emergency management responsibility.

NOTE ON TERMINOLOGY: Within the Emergency Management System (EMS), “planning” includes the development of emergency plans and procedures and the identification of personnel and resources necessary to provide an effective response. “Preparedness” is the procurement and maintenance of resources, training of personnel, and exercising of the plans, procedures, personnel and resources. “Response” is the implementation of the plans during an emergency to mitigate consequences and to initiate recovery.

(a) **Planning and Preparedness Commensurate with Hazards**. Because of the wide range of activities and operations under DOE's authority, standards and criteria suited to one type of facility or hazard may be inappropriate for another. To deal with this diversity, while assuring an adequate overall state of preparedness, DOE Order 151.1C requires that the details of each feature be tailored to the unique hazards of the specific facility. This approach ensures a more complete and quantitative understanding of the hazards while providing for focused and cost-effective emergency planning and preparedness.

(b) **Integrated Planning for Health, Safety and Environmental Emergencies**. A wide variety of different types of Operational Emergencies can occur at DOE operations. Some may involve loss of control over radioactive or other hazardous materials unique to DOE operations, while others may involve security, transportation activities, natural phenomena impacts, environmental damage, or worker safety and health concerns. Planning, preparedness and response requirements applicable to DOE facilities and activities for some types of emergency conditions are specified by other agencies. For example, Federal regulations on occupational safety, environmental protection and hazardous waste operations have consequent “emergency planning” requirements. Rather than meet these requirements piecemeal through separate programs, each DOE/NNSA site/facility shall have an Operational Emergency Base Program that implements the requirements of applicable Federal, State, and local laws/regulations/ordinances for fundamental worker safety programs (e.g., fire, safety, and security). These requirements are not unique to DOE/NNSA operations.

(c) **Classification of Emergencies and Graded Response**. Operational Emergencies involving the airborne release of hazardous materials are grouped into one of three classes according to magnitude or severity. Classification of events is intended to promote more timely and effective response by triggering planned response actions generally appropriate to all events of a given classification. This principle, termed “graded response”, is embodied in DOE Order requirements and is important to the effective management of response resources.

(d) **Tiers of Emergency Management Responsibility**. Within the EMS, responsibility for emergency management extends from the individual facility level to the cognizant DOE Field Element, and culminates at the cognizant Headquarters Program Secretarial Office (PSO). The responsibilities vested at each level of the hierarchy are specified in DOE Order 151.1D (DOE, 2016b). The responsibility and authority for recognizing, classifying, and mitigating emergencies always rests with the facility staff. The head of the cognizant Field Element oversees the response of contractors and supports the response with communications, notifications, logistics, and coordination with other DOE elements. The DOE Headquarters (HQ) Emergency Operations Center (EOC) receives, coordinates, and disseminates emergency information to HQ elements, the cognizant PSO, Congressional offices, the White House, and other Federal Agencies.

9.1.2 Requirements Pertaining to All DOE Operations

DOE Order 151.1D (DOE, 2016b) identifies program elements that comprise each DOE facility emergency management program. The elements form a standard framework, with the details of each program element varying according to the nature and magnitude of the facility hazards and other factors. The Order requires that a Hazard Survey be used to identify the generic emergency events or conditions that define the scope of the emergency management program. Where hazardous materials, such as plutonium, are present in quantities exceeding the quantity that can be “easily and safely manipulated by one person” and whose potential release would cause the impacts and require response activities characteristic of an Operational Emergency, the Order requires a facility-specific Emergency Planning Hazards Assessment (EPHA) be conducted and the results used as the technical basis for the program element content. Using the results of an objective, quantitative, and rigorous hazards assessment as a basis, each program is configured to the specific hazards and response needs of the facility. Detailed guidance on the implementation of the Order requirements has been published by the DOE Office of Emergency Management (DOE, 2007d, 2007e, 2007f, 2007g). These EMGs specify acceptable methods of meeting the EMS Order requirements.

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Individual guides have been published for the technical planning basis (i.e., Hazards Survey/EPHA) processes and for programmatic and response program elements.

9.2 SPECIFIC GUIDANCE ON EMERGENCY MANAGEMENT FOR PLUTONIUM FACILITIES

This section provides technical guidance that is specifically applicable to the development and implementation of emergency management programs for plutonium facilities. It is intended to supplement, not replace, the more general recommendations provided in the EMG.

9.2.1 Technical Planning Basis

9.2.1.1 Hazards Survey

The Operational Emergency Base Program shall be based on a Hazards Survey. A Hazards Survey is an examination of the features and characteristics of the facility or activity to identify the generic emergency events and conditions (including natural phenomena such as earthquakes and tornadoes; wild land fires; and other serious events involving or affecting health and safety, the environment, safeguards, and security at the facility) and the potential impacts of such emergencies.

Each Hazards Survey shall—

(a) identify (e.g., in matrix or tabular form) the emergency conditions (e.g., fires, work place accidents, natural phenomena, etc.);

(b) describe the potential health, safety, or environmental impacts;

(c) indicate the need for further analyses of hazardous materials in an EPHA, based on the results of a hazardous material screening process; and

(d) identify the planning and preparedness requirements that apply to each type of hazard.

A Hazardous Material Screening Process shall identify specific hazardous materials and quantities that, if released, could produce impacts consistent with the definition of an Operational Emergency. The potential release of these materials to the environment requires further analysis in an EPHA. The release of hazardous materials less than the quantities listed below does not require quantitative analysis in an EPHA.

(a) In general, to meet the definition of an Operational Emergency, the release of a hazardous material shall: immediately threaten or endanger personnel and emergency responders who are in close proximity of the event; have the potential for dispersal beyond the safety of onsite personnel or the public in collocated facilities, activities, and/or offsite; and have a potential rate of dispersal sufficient to require a time-urgent response to implement protective actions for workers and the public.

(b) The hazardous material screening process shall identify all hazardous materials in a facility/activity that require further analysis in an EPHA. Specifically, for radioactive materials:

(1) All radioactive materials in a facility/activity shall be subjected to a hazardous material screening process.

(2) Radioactive materials that may be excluded from further analysis in an EPHA include: sealed radioactive sources that are engineered to pass the special form testing specified by the Department of Transportation (DOT) or ANSI; materials in solid form for which there is no plausible dispersal mechanism; materials stored in DOT Type B shipping containers with overpack, if the Certificates of Compliance are current and the materials stored are authorized by the Certificate; and, materials used in exempt, commercially available products.

(3) Radioactive hazardous materials that require further analysis in an EPHA include the radioactive materials listed in DOE-STD-1027-92 in quantities greater than the Category 3 values given in Attachment 1, Table A.1., of that Standard.

9.2.1.2 Emergency Planning Hazards Assessment (EPHA)

Unique properties and characteristics of plutonium and its compounds may need to be considered at certain steps in the EPHA process.

(a) **Description of Facility and Operations.** The properties of the hazardous material do not significantly affect the manner in which this step of the EPHA is performed, except to the extent that plutonium safety considerations may mandate more detailed descriptions of certain facility physical or operational features.

(b) **Characterizing the Hazards.** The objective of this step is to describe the hazardous materials in sufficient detail to allow accurate modeling of releases and calculation of consequences. The following properties of plutonium and its compounds influence the release potential and consequences.

- Chemical and physical form. The chemical toxicity of plutonium and its compounds is of much less concern than the radiotoxicity of the plutonium. However, the chemical and physical form may strongly influence the release potential. Plutonium metal oxidizes readily in humid air at elevated temperatures to form loosely-attached oxide particles, a source of readily dispersible airborne and surface contamination. Plutonium metal fines and turnings can ignite spontaneously in the presence of air, creating aerosol-size oxide particles and providing energy to disperse them. Also, some plutonium compounds may ignite violently on contact with air, water or hydrocarbons (Benedict, et al., 1981).

- Solubility. The CED per unit activity inhaled is about three times greater for plutonium of material type M than for material type S. No plutonium compounds of material type F are generally recognized.

- Particle size. Particle size distribution has a large effect on the radiotoxicity of inhaled materials. Larger particles tend to be cleared rapidly from the upper respiratory regions and swallowed, thereby delivering little radiation dose to the lung tissues. Because plutonium is poorly absorbed in the gut, very little dose is attributed to the larger particles that are cleared from the body by this process. Small particles are deposited deeper in the lung and are cleared very slowly, producing a much larger dose per unit activity inhaled. Extremely small particles tend to be exhaled and not deposited.

- Isotopic mixture. Characterization of the isotopic mixture is important to the accuracy of both dose calculations and contamination measurements. When the inventory or quantity released is expressed as the total activity (Ci or Bq) of a mixture of isotopes, the total often includes the ^{241}Pu activity. Because ^{241}Pu decays almost exclusively by beta emission, it contributes little to the internal dose from a mixture of Pu isotopes. Also, the fraction of ^{241}Am (from decay of ^{241}Pu) in plutonium can vary greatly, depending on the degree of irradiation and the time since the plutonium was chemically separated from the reactor fuel. Characterization of contamination from a plutonium mixture is often done by detecting the low-energy photons emitted by ^{241}Am, which requires knowledge of the activity of ^{241}Am compared to the other isotopes in the mixture.

(c) **Developing Event Scenarios.** The properties of the hazardous material do not significantly affect the manner in which this step of the hazards assessment is performed.

(d) **Estimating Potential Event Consequences.** For the scenarios developed in the previous step, this step determines the area potentially affected, the need for protective actions, and the time available to take those actions. The way these consequences are determined depend on properties of the hazardous material.

For plutonium and its compounds, inhalation during plume passage is the most important exposure process in the early phase of an emergency. After passage of a plume, exposure to material deposited on the ground will dominate. Therefore, the following features should be considered when selecting and applying calculation models:

- Inhalation pathway dose. For any realistic mixture of plutonium isotopes, the great majority of the dose will be by the inhalation pathway. Therefore, the model selected to estimate consequences of an atmospheric plutonium release shall be able to calculate the TED to an individual exposed by inhalation.

- Plume depletion during transport. As it is transported downwind, an aerosol plume will be depleted by gravitational settling of particles. Because of the high density of plutonium and its compounds, this depletion effect can be very significant in reducing the dose. Therefore, a

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consequence model that accounts for plume depletion by gravitational settling should be used. When analyzing consequences of any postulated accidental criticality, any model selected should account for the decay during transport of short-lived fission product gases.

- Ground deposition. Following passage of a plume, the amount of plutonium deposited on the ground will determine whether long-term intervention to minimize the dose to the resident population will be required. The consequence model selected should calculate ground deposition to support protective action planning.

9.2.2 Program Elements

Properties and characteristics of plutonium and its compounds shall be considered in formulating the emergency management program elements. Following are specific program element considerations related to the hazardous properties of plutonium.

9.2.2.1 Programmatic Elements

The specific properties of the hazardous material do not significantly affect the content of the programmatic program elements: Program Administration, Training and Drills, Exercises, and Readiness Assurance.

9.2.2.2 Response Elements

(a) **Emergency Response Organization.** The primary influence of plutonium's hazardous properties on the Emergency Response Organization (ERO) is in the staffing of the consequence assessment component. As will be discussed in e) below, staff should be assigned to the ERO who are knowledgeable of and able to quantitatively evaluate the radiological aspects of the hazard.

(b) **Offsite Response Interfaces.** The specific properties of the hazardous material do not significantly affect the content of this program element.

(c) **Operational Emergency Event Classes.** As with all hazardous materials, classification of emergencies for plutonium facilities should be based on the predicted consequences at specific receptor locations, as compared with numerical criteria for taking protective action (TED). The classification of the postulated event or condition should be determined during the EPHA process and the observable features and indications identified as Emergency Action Levels (EALs) for that event/condition.

(d) **Notification.** The specific properties of the hazardous material do not significantly affect the content of this program element.

(e) **Consequence Assessment.** As discussed in section 9.2.1.2 d, models and calculation methods used for consequence assessment should be appropriate to the physical, chemical, and radiological properties of the hazards. Models used to calculate and project the radiological consequences of a release of plutonium should be the same ones used in the EPHA process. If the same models are not used, the differences between outputs should be characterized and documented to avoid the potential for confusion and indecision during response to an actual emergency.

Environmental monitoring capability for assessing consequences of a plutonium release should conform to several general principles.

- Procedures for measurement of airborne plutonium should provide for timely analysis and reporting of results in units that correspond to decision criteria. Decision points based on initial alpha screening measurements with field instruments should account for the expected levels of radon progeny collected on the air sample media. Alternatively, portable survey instruments capable of performing alpha spectroscopy measurements can be used to provide rapid isotopic analysis of plutonium collected on sample media. Precautions should be taken when using radon stripping instrumentation. One site found that it would not work with mixed alpha and beta emitters such as Uranium and Thorium. Another site found the same result using Strontium and Plutonium.

- Measurement of plutonium deposition should be planned and proceduralized to yield results that correspond to those needed by the predictive models used for emergency response. The correlation between direct or indirect radioactivity measurements (in units of activity) and measurement methods that give mass or concentration of plutonium in a sample should be established for standard sample sizes, collection efficiencies, and the expected isotopic mixture(s) of material that might be released. Information on expected isotopic mixture should be available for converting the results of measurements made with photon-sensitive instruments, such as the Fiddler and Violinist, into plutonium activity per unit area.

- If the potential exists for release of plutonium in conjunction with materials of high chemical toxicity, it is generally not practical to plan on use of survey teams to quantify concentrations in a plume. The high risk to survey personnel, the protective equipment necessary to minimize that risk, the time needed to prepare and deploy a team for such a survey and the limited value of the information that could be gained all weigh against this approach to assessing the consequence of a highly toxic release.

- Continuous environmental air samples are taken around the perimeter of some plutonium facilities for environmental reporting purposes.

  Consequence assessment procedures should provide for the rapid retrieval and analysis of sample media from any fixed samplers that may be operating in an area affected by a plutonium release. The procedures should specify the type of measurements to be done on those sample media, including any instrument settings, conversion factors, or adjustments needed to produce useful results in the shortest time possible.

(f) **Protective Actions.** The Protective Action Guides (PAGs) published by the U.S. Environmental Protection Agency (EPA, 2017) have been adopted by DOE as its basic protective action criteria for planning and response. The terms "PAG" and "EPA Protective Action Guides" used in the Order should be interpreted as follows:

- A projected dose equivalent of 10 mSv (1 rem) total effective dose equivalent to reference man, where the projected total effective dose equivalent is the sum of the effective dose equivalent from exposure to external sources and the committed effective dose equivalent from inhalation during the early phase; or
- A projected committed dose equivalent to the adult thyroid of 50 mSv (5 rem); or
- A projected committed dose equivalent to the skin of 500 mSv (50 rem).

Facilities having substantive and persuasive arguments for using other protective action threshold values may propose values that are specific to their radioactive material holdings and operations. Any alternative proposals should be supported by an analysis that addresses the four principles that form the basis for the selection of the EPA PAG values and the other considerations utilized in the selection process, as discussed in Appendix C of the EPA 400-R-92-001.

(g) **Medical Support.** If the potential exists for large intakes of plutonium, the emergency management program should include specific planning for the quantification of exposure, diagnosis of health effects, and treatment. Medical facilities providing emergency medical support should be provided with references relating to plutonium toxicity and treatment protocols. Criteria for implementing treatments such as surgical excision of contaminated tissue, lung lavage, or use of chelating agents should be discussed with the medical staff and sources of real-time advice and assistance should be identified.

(h) **Recovery and Reentry.** The specific properties of the hazardous material do not significantly affect the content of this program element.

(i) **Public Information.** The specific properties of the hazardous material do not significantly affect the content of this program element.

(j) **Emergency Facilities and Equipment.** Except for instruments and analysis methods used in consequence assessment, little by way of specialized facilities and equipment will be required to meet the emergency management program needs of plutonium facilities. Equipment and analytical techniques for detection and measurement of plutonium in environmental sample media should have sufficient sensitivity to measure levels at or below those corresponding to decision criteria. Whereas larger sample sizes, chemical processing, or longer counting times may be used to reduce the limit of detection for routine environmental surveillance, time constraints may dictate that more sensitive techniques be available to meet the information needs of emergency response.

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10.0 DECONTAMINATION AND DECOMMISSIONING

At the end of the useful life of a facility, activities are undertaken to restore the facility to non-contaminated status and permit its unrestricted use. These activities are typically termed decontamination and decommissioning (D&D).

Although plutonium facilities are no longer useful and operational activities are no longer conducted, measures shall be continued to control the residual radioactivity. The decision may be made to undertake a D&D program to minimize or eliminate long-term institutional control. This may be done in a variety of ways, most of which may be termed D&D. The exception is converting the facility to some other nuclear use. With the elimination of the DOE weapons production mission, more plutonium-contaminated facilities will require D&D in the near future.

This chapter provides guidance on establishing and implementing an effective D&D program. Major topic areas include regulations and standards, design features, D&D program, D&D techniques, and D&D experience. This chapter concentrates on the radiation-protection aspects of D&D at plutonium-contaminated DOE facilities.

10.1 REGULATIONS AND STANDARDS

The standards that apply to the decommissioning of a plutonium-contaminated facility include virtually all of those that were applicable during facility operations, (e.g., 10 CFR 835, DOE P 450.1 and 10 CFR 851) plus some additional ones such as 10 CFR 835.1002(d). The occupational safety and radiation dose limits, safety management requirements, radioactive and hazardous chemical disposal regulations, and transportation requirements are unaffected by the activity to which they apply.

No single DOE regulation covers all D&D requirements due to the wide variety of issues encompassed by D&D. These issues include project management, environmental surveillance, health and safety of workers and the public, engineering design, characterization survey techniques, D&D techniques, waste management, and waste transport. The primary DOE Orders pertaining to D&D activities are DOE Order 430.1C, Real Property Asset Management (DOE, 2016c); DOE Order 458.1, Ch. 3, Radiation Protection of the Public and Environment (DOE, 2011c); DOE O 231.1B, Environment Safety and Health Reporting (DOE, 2001g); DOE Order 420.1C, Facility Safety (DOE, 2012b). The DOE operations offices may have implementation procedures corresponding to these Orders that which contractors will also need to comply.

DOE Order 430.1C, Real Property Asset Management (DOE, 2016c), provides the requirements to ensure a disciplined, systematic, and coordinated approach to project management. All projects, including D&D projects, should have clearly defined goals and objectives that support program requirements. Specific objectives include (1) promoting project execution that meets technical, schedule, and cost objectives, (2) meeting all applicable environmental, health and safety, and quality assurance requirements, and (3) avoiding a commitment of major resources before project definition. Good program management techniques should consider D&D costs as part of the lifecycle cost and select a tentative D&D method during the facility design phase.

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DOE Order 458.1, Ch.3, Radiation Protection of the Public and Environment (DOE, 2011c), provides radiological protection requirements and guidelines for cleanup of residual radioactive material and management of the resulting wastes and residues and release of property. This DOE Order establishes a basic public dose limit for exposure to residual radioactive material (in addition to naturally occurring "background" exposures) of a 100-mrem (1-mSv) effective dose equivalent in a year. A more detailed discussion is presented below in Section 10.1.3.

DOE O 420.1C, Facility Safety (DOE, 2012b), establishes facility safety requirements related to: nuclear safety design, criticality safety, fire protection and natural phenomena hazards mitigation.

DOE O 231.1B Environment, Safety and Health Reporting (DOE, 2001g), ensures collection and reporting of information on environment, safety and health that is required by law or regulation to be collected, or that is essential for evaluating DOE operations and identifying opportunities for improvement needed for planning purposes within the DOE.

10.1.1 Other Regulations

The D&D of most plutonium-contaminated facilities will involve cleanup of a combination of radioactive wastes, hazardous wastes, and mixed wastes. Some other Federal regulations not already discussed that are applicable to the cleanup and disposal of these wastes are summarized in this section along with the DOE guidance on implementation. This is not an all inclusive list. It is the facility responsibility to identify applicable requirements and ensure compliance.

-- National Environmental Policy Act (NEPA) (USC, 1970) and 40 CFR 1500 (CEQ, 1992)
- This act established a national policy to ensure that environmental factors are considered in any Federal agency's planning and decision making. DOE P 451.1, National Environmental Policy Act Compliance Program (DOE, 2017a), defines DOE responsibilities and procedures to implement NEPA. The decommissioning of a DOE plutonium facility will require a determination of whether or not the action is a "major or significant government action adversely affecting the environment" in accordance with NEPA. If it qualifies as such an action, an environmental assessment (EA) or environmental impact statement (EIS) will be required. An EA or EIS will need to discuss the amount of material that will remain onsite and its effect, in addition to addressing the alternatives. The alternatives will include retaining radioactive material onsite under DOE control, cleaning the site to a level that would be acceptable for unrestricted release, and the null or no-action alternative of "walking away" from the site. If the action does not require an EA or EIS, either because the possible adverse effects are insignificant or because decommissioning was adequately addressed in a preoperational or other EA or EIS, then the decommissioning can proceed in accordance with the information contained in other applicable regulations.

-- Resource Conservation and Recovery Act (RCRA) (USC, 1976a) - This act authorizes the EPA and the States to regulate hazardous and solid wastes.

-- Comprehensive Environmental Response, Compensation, and Liability Act (USC, 1980) and 40 CFR 300 (EPA, 2018c) - This act requires the identification and cleanup of inactive hazardous waste sites by responsible parties, and imposes certain response and reporting requirements for releases of hazardous substances.

-- Superfund Amendments and Reauthorization Act (USC, 1986) and 40 CFR 300 (EPA, 2018c).

Interagency agreements can also exist between DOE, EPA, state, and local agencies (Daugherty, 1993). Any special arrangement agreed to as part of an interagency agreement will need to be honored during the D&D activities.

10.1.2 Residual Radioactivity Levels

A primary concern in the D&D of any nuclear facility is the level of residual radioactivity that may be permitted for unrestricted use. However, the emphasis of this document is on occupational radiological protection. See Section 4.2.4 for guidance on contamination monitoring in the workplace. Additional information on acceptable residual levels may be found in the following sources. This list is not inclusive and facilities shall determine the applicable requirements. For clearance of DOE property for use by the public, DOE O 458.1 requirements are applicable. The U.S. Nuclear Regulatory Commission (NRC) in Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors (AEC, 1974), provide definitive values for acceptable surface contamination levels for termination of operating licenses for nuclear reactors and for materials, equipment, and facilities and ANSI/HPS N13.12 (ANSI, 1999b) and IAEA Safety Guide RS-G-1.7, *Application of the Concepts of Exclusion, April 2005, Exemption and Clearance,* provide values for materials and equipment.

DOE Order 458.1, Ch. 3, Radiation Protection of the Public and Environment (DOE, 2011c), provides the following DOE guidelines for cleanup of residual radioactive material, management of the resulting wastes, and release of property. The basic public dose limits for exposure to residual radioactive material in addition to natural background exposures is a 100-mrem (1-mSv) effective dose equivalent in a year from all sources and pathways. The effective dose equivalent in a year is the sum of the effective dose equivalent from exposures to radiation sources external to the body during the year plus the CED from radionuclides taken into the body during the year. Because the limit applies to all sources and pathways DOE recommends use of a 25 mrem in a year dose constraint to ensure that exposures from this source (residual radioactive material) does not combine with other non-background sources to cause doses in excess of 100 mrem in a year.

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DOE Order 458.1, Ch. 3 (DOE, 2011c) also provides the following guidelines for (1) residual concentrations of radionuclides in soil, (2) concentrations of airborne radon decay products, (3) external gamma radiation, (4) surface contamination, and (5) radionuclide concentrations in air or water:

-- **Residual radionuclides in soil** - Generic guidelines for thorium and radium (^{226}Ra, ^{228}Ra, ^{230}Th, and ^{232}Th) are 5 pCi/g averaged over the first 15 cm of soil below the surface and 15 pCi/g averaged over 15-cm-thick layers of soil more than 15 cm below the surface. For other radionuclides in soil (e.g., plutonium), specific guidelines should be derived to be as low as reasonably achievable below the basic dose limit and consistent with DOE dose constraints. It should be supported by means of an environmental pathway analysis using specific property data where available. Residual concentrations of radioactive material in soil are defined as those in excess of background concentrations averaged over an area of 100 m^2.

-- **Airborne radon decay products** - Applicable generic guidelines are found in 40 CFR 192 (EPA, 2018b). In any occupied or habitable building, the objective of remedial action should be, and a reasonable effort should be made to achieve, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 WL. Remedial actions by DOE are not required to comply with this guideline when there is reasonable assurance that residual radioactive material is not the source of the radon concentration.

-- **External gamma radiation** - The average level of gamma radiation inside a building or habitable structure on a site to be released without restrictions should not exceed the background level by more than 20 μR/h.

-- **Residual Surface Activity** - The DOE guidelines on transuranic surface contamination levels are consistent with NRC Regulatory Guide 1.86 and are discussed in a DOE memorandum dated November 17, 1995, "Application of DOE 5400.5 requirements for release and control of property containing residual radioactive materials," the guideline values are as follows:

<u>Guidelines</u>

Removable Contamination	20 dpm/100 cm^2
Total (Fixed plus Removable Contamination)	100 dpm/100 cm^2
Maximum	300 dpm/100 cm2

The order also permits alternative surface activity guidelines that ALARA-based and derived using pathway dose analysis.

-- **Residual radionuclides in air and water -** Residual concentrations of radionuclides in air shall not cause members of public to receive an effective dose equivalent greater than 10 mrem (0.1 mSv) in one year [DOE Order 458.1 (DOE, 2011c)]. In 40 CFR 141, National Primary Drinking Water Regulations (EPA, 2018a), the EPA provides a limit of 4 mrem/y annual dose equivalent to the whole body or any internal organ of any member of the public from manmade radionuclides in drinking water.

The NRC has updated their decommissioning regulations and criteria, see 10 CFR Part 20 subpart E. NRC established a 25 mrem in a year plus ALARA requirement that is to be demonstrated by use of pathway dose analyses to derive criteria and surveys to demonstrate properties meet the derived criteria. Screening levels are also provided in the associated NRC guidance documents that may be used instead of the derived criteria. Both DOE and NRC allow use of RESRAD or RESRAD-build for deriving criteria. NRC screening levels are not applicable to DOE operations and may be used only with DOE pre-approval.

The derivation of criteria requires calculation of dose to members of the general population. The scenarios for exposure will have to include all exposure pathways that are credible under the proposed disposition. If the site is part of a closely guarded government reservation, certain pathways may be eliminated, such as the use of well water directly from the site and ingestion of significant quantities of fruits and vegetables grown on the site. However, if the site will be released for unrestricted use, such scenarios should be considered. The computer codes used for calculation of dose to the public from decommissioned facilities will include the currently accepted exposure models and site-specific or maximum credible parameters for exposure pathways.

A multi-agency effort has developed measurement and decision criteria applicable to D&D projects. The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) has been published (DOE, 2000). It provides detailed survey techniques applicable to the D&D of DOE facilities. A related document for sampling and analysis of environmental samples has also been approved for interagency use: *Multi-Agency Radiological Laboratory Analytical Protocols Manual* (MARLAP) EPA 402-B-04-001A, July 2004.

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10.2 DESIGN FEATURES

Design of the facility should allow easy D&D of equipment and materials. Details on designing facilities for ease of decommissioning are discussed in the following sections. 10 CFR 835.1002 and Appendix C of this document provide additional guidance on facility design.

10.2.1 Building Materials

In general, the design features that aid in contamination control during operation also facilitate decommissioning. The inclusion of all the building materials suggested in this section may be cost-prohibitive, but they should be considered if the budget allows. The maintenance procedures that are used during operation are also important in controlling the spread of contamination to clean areas and, therefore, they facilitate decommissioning, too.

Less permeable building materials are more easily decontaminated. Any concrete with uncoated surfaces that comes in contact with plutonium solutions or plutonium contaminated air will require surface removal and disposal as radioactive waste at the end of its life. If there are cracks through which contaminated solutions have penetrated, the entire structure may need to be disposed of as radioactive waste.

Metal surfaces may also require decontamination. In general, the more highly polished the surface, the easier it will be to decontaminate. If feasible, all stainless steel that will come into contact with plutonium should be electropolished before being placed into service. If high-efficiency particulate air (HEPA) filtration has failed at any time during facility operation, roofs may require decontamination. Metal roofs are easiest to decontaminate, but even these may contribute to the volume of radioactive waste unless unusual measures are taken to clean them. Built-up and composition roofs will be difficult to clean to unrestricted release levels.

Interior surfaces are most easily cleaned if they were completely primed and painted before the introduction of radioactive materials into the facility. If interior surfaces are repainted during operation, their disposal as clean waste is likely to require removal of the paint. However, if the paint has deteriorated, cleaning for unrestricted use may be as difficult as if the material had never been painted. Wood will almost certainly become contaminated, as will plasterboard and other such materials.

Floor surfaces are likely to be a problem. Concrete should be well sealed and covered with a protective surface. Single sheet, vinyl flooring with heat-sealed seams is preferable to asphalt or vinyl tile because it is more easily cleaned. If the floor needs resurfacing, it is preferable to overlay new flooring material rather than remove the old material and expose the underlying floor.

Carpets are not recommended because they are difficult to clean and survey and bulky to dispose of and they do not adequately protect the underlying surface. In some areas, such as control rooms, their use may be justified by noise control requirements; however, their contamination control limitations should be considered. If used, carpets should be surveyed frequently and disposed of as radioactive waste when they become contaminated.

10.2.2 Ventilation Systems

In addition to decommissioning considerations, the design of the ventilation system will depend on the operations that will be conducted in the facility. Adequate air flow for all operations and good design practices will help keep the facility clean during operations and will facilitate decommissioning. Fiberglass duct work may present a fire hazard and may be more difficult to decontaminate than stainless steel, especially stainless steel that has been electropolished. Welded joints are less likely to collect contamination than bolted ones; however, bolted joints are easier to remove and the most contaminated areas are readily accessible for cleaning.

Filters should be positioned in ventilation systems to minimize contamination of ductwork (e.g., filtration of glove-box exhaust air before it enters a duct leading to a plenum).

10.2.3 Piping Systems

Potentially contaminated piping systems that are imbedded in concrete are a common and relatively expensive decommissioning problem. Most often, they shall be sealed and removed last, after all other radioactive material has been removed and the building is being demolished by conventional methods. Often, they provide the major impetus for demolishing a building rather than converting it to some non-nuclear use. For this reason, it is best to run pipes in chases or tunnels that have been lined (usually with stainless steel) to prevent contamination from penetrating building surfaces. To minimize hand jackhammer work required during decommissioning, floor drains should not be enclosed in concrete.

10.2.4 Soil-Contamination Considerations

Depending on the activity levels found, locations where contaminated effluents have penetrated the ground may require excavation during decommissioning. The facility design should minimize such areas. Particular attention should be paid to storm runoff from roofs, storage areas, contaminated equipment storage, and liquid waste treatment impoundments (including sanitary sewage systems if they may receive some small amount of contamination during the life of the facility.)

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10.2.5 Other Features

Installed decontamination and materials-handling equipment that facilitates operation and maintenance generally facilitates decommissioning in two ways. First, it can be used for its intended purposes of cleaning and moving equipment during the decommissioning phase. Even more important, it usually contributes to a cleaner, better maintained facility, where nonfunctional equipment is moved out when it is no longer needed and work surfaces are kept free of spreadable contamination.

Other features include the following:

- Minimizing service piping, conduits, and ductwork;
- caulking or sealing all cracks, crevices, and joints;
- using modular, separable confinements for radioactive or other hazardous materials to preclude contamination of fixed portions of the structure;
- using localized liquid transfer systems that avoid long runs of buried contaminated piping;
- using equipment that precludes the accumulation of radioactive or other hazardous materials in relatively inaccessible areas, including curves and turns in piping and ductwork;
- using designs that ease cut-up, dismantling, removal, and packaging of contaminated equipment from the facility;
- using modular radiation shielding, in lieu of or in addition to monolithic shielding walls;
- using lifting lugs on large tanks and equipment; and
- using fully drainable piping systems that carry contaminated or potentially contaminated liquids.

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10.3 DECONTAMINATION AND DECOMMISSIONING PROGRAM REQUIREMENTS

Planning for facility decommissioning should be initiated during the design phase for new facilities and before termination of operations for existing operational facilities. To assist in D&D activity planning the Office of Environmental Management distributed the "Decommissioning Resource Manual." Refer to that document for guidance.

Requirements relating to occupational radiological protection include (this is not an all inclusive list, facilities shall determine the applicable set of requirement):

DOE Order 430.1C, Real Property Asset Management (DOE, 2016c), contains the requirements by which all DOE projects shall be managed; It requires that a project management plan be developed for major system acquisitions and major projects and states that environment, safety, and health technical requirements for project design and implementation should be included in the work-plan section of the project management plan.

10.4 DECONTAMINATION AND DECOMMISSIONING TECHNIQUES

This section concentrates on decontamination techniques to be used in the final decommissioning of a plutonium-contaminated facility for unrestricted release. Some of these techniques are similar to those used during routine operations (e.g., some equipment and building surface decontamination). Contamination detection methods are similar for routine and D&D operations and are discussed in Chapter 4.

10.4.1 Equipment and Surface Decontamination

Decontamination of surface areas may be as simple as hosing off the floors with water, washing surfaces with detergent and water, or wiping with household dust cloths. Waste material generated from decontamination activities (e.g., water and wipe material) shall be contained and disposed of as radioactive waste. For some locations, vacuuming the surfaces may be appropriate. If vacuuming is used, HEPA-filtered vacuum systems are required to keep airborne radioactive material out of the vacuum exhaust.

For some operations, periodic surface flushing with water may be adequate to maintain acceptable contamination levels. Precautions should ensure control and collection of run-off water so that material may be recovered and waste water analyzed before discharge. Depending upon which isotope of plutonium is involved, geometrically safe containers may be required for collecting and holding the liquid.

Depending upon the physical and chemical form of the plutonium and the type of surface, plutonium may become imbedded in the surface. Removal of embedded material may require physical abrasion, such as scabbling, grinding, sand blasting, or chipping, or it may be accomplished using chemical etching techniques. If the surface is porous, complete

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replacement could be necessary. The use of high-pressure water (hydroblasting) has been quite successful for metal and concrete surfaces.

Ultrasonic cleaning techniques (electropolishing) or chemical baths may be useful for decontamination of high-cost items if the chemicals used are compatible with the material to be cleaned.

A description of different decontamination techniques is found in DOE/EV/10128-1, DOE Decommissioning Handbook (DOE, 1980), and publications by Allen (1985) and the Electric Power Research Institute (EPRI, 1989). The DOE Decommissioning Handbook also includes guidance on decontamination techniques, assessment of environmental impacts, disposition of wastes, and preparation of decommissioning cost estimates.

10.5 DECONTAMINATION AND DECOMMISSIONING EXPERIENCE

Considerable experience has been gained in D&D of commercial plutonium facilities, as discussed in Hoovler et al. (1986), Denero et al. (1984), and Adams et al. (1982). Hoovler et al. (1986) discuss the decommissioning programs carried out at two Babcock and Wilcox buildings in Lynchburg, Virginia, which housed plutonium/uranium fuel development laboratories. They include information on decommissioning and quality assurance plans, conducting D&D work, performing radiological surveys before and after D&D work, and disposing of the waste. Denero et al. (1984) discuss the D&D of the Westinghouse Nuclear Fuel Facility at Cheswick, Pennsylvania. They describe the facility and its operations, nondestructive assay techniques, equipment required for dismantling and packaging the waste, and management of the TRU waste. Adams et al. (1982) discuss the complete D&D of the Westinghouse Advanced Reactors Division Fuel Laboratories at the Cheswick, Pennsylvania, site. The report describes the D&D plans, the EA written for the operation, the quality assurance plan, and the health physics, fire control, and site emergency manuals written for the operation.

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Discussions of D&D activities at several DOE plutonium facilities are provided by Adkisson (1987), Bond et al. (1987), and King (1980), as well as by Shoemaker and Graves (1980), Garner and Davis (1975), Wynveen et al. (1982), Hunt et al. (1990), Freas and Madia (1982), and Garde et al. (1982a, 1982b). They describe D&D activities that took place in several types of plutonium facilities, including fabrication facilities, research and development laboratories, and a storage facility. Plutonium-contaminated glove boxes, hoods, ventilation ductwork, laboratory equipment, structural components (i.e., walls and floors), and filter banks were decontaminated. Typically, decontamination methods included wiping with a damp cloth or mop, using strippable coatings, mechanical spalling of concrete floor surfaces, and fixating contamination on a piece of equipment (e.g., a hood), followed by disassembling the item inside a contamination control enclosure.

Some lessons learned from past studies include the following:

-- Waste management planning should begin early in the D&D planning stages and consider the following:

  - The possibility exists that there may be more stringent regulations for shipping hazardous or radioactive wastes than disposing of it and

  - Compliance with all applicable waste management requirements may be difficult (e.g., WIPP has unique limits on Beryllium content, typically <1%, for criticality safety due to its disposal array being so large).

-- It is difficult to decontaminate some items with inaccessible surfaces to less than the TRU limit (100 nCi/g) so that they can be disposed of as LLW. In some situations, it may be possible to decontaminate to <100 nCi/g of TRU, but the decontamination process may generate a large volume of liquid waste or be time-consuming enough to prohibit its use.

-- Temporary enclosures, with appropriate venting, are effective in controlling contamination when reducing the size of large equipment such as glove boxes. Any loose contamination on the equipment should be fixed before placing it in the enclosure.

-- Criticality safety issues regarding the geometry of any waste material containing fissile material need to be considered.

Adkisson (1987) reported on the decommissioning of a plutonium fuel fabrication plant at the Sequoyah Fuels Corporation's Cimarron Facility, located in north-central Oklahoma. Process equipment, glove boxes, tanks, piping, and ventilation ducts required decontamination. Controlling personnel exposures, maintaining containment of radioactive material during the dismantling of contaminated items, and reducing the volume of TRU material were the primary considerations during the decommissioning activities. A large modified glove box provided containment for dismantling and cutting up the various equipment using a plasma-arc unit. A passive, gamma-ray nondestructive assay technique (heavily shielded NaI detector with collimator) was used to measure the plutonium content of cut-up pieces. Finally, the loaded waste drums were measured using a waste drum counter to ensure that plutonium levels were less than 100 nCi/g.

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A number of plutonium-contaminated facilities have been decommissioned at Mound Laboratory (Bond et al., 1987). Interdepartment management teams, including representatives from program management, operations, project engineering, maintenance, technical support, and environmental, safety, and health were established for the D&D projects. The team met monthly to discuss program status and they met quarterly with DOE staff. A graded D&D approach was used. First, standard cleaning (e.g., wiping with a damp cloth) and flushing techniques were used to remove loose contamination. Then, more aggressive decontamination methods were performed inside temporary enclosures. Finally, glove boxes and equipment that could not be decontaminated to unrestricted release levels were cut into sections using a plasma-cutting method and then packaged as waste. The plasma-cutting method generated less smoke, thus reducing the particulate accumulation on the HEPA filters.

During cleanup of a plutonium-contaminated storage facility, strippable fixatives were used as a contamination control and a decontamination method (King, 1980). Fixatives in combination with cheese cloth were used to clean smooth vertical surfaces and difficult-to-reach areas. The cheese cloth was placed on the area to be cleaned and then sprayed with a fixative. The cheese cloth and fixative were then stripped from the surface, removing contamination in the process. Accidental criticalities can be a concern when disposing of this material that contains fissile material contamination, as discussed in Section 8.0, and criticality safety specialists should be consulted. Facility personnel also need to determine if the fixative is classified as a hazardous material and dispose of it accordingly.

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APPENDIX A

GLOSSARY

Terms used consistent with their regulatory definitions.

abnormal situation: Unplanned event or condition that adversely affects, potentially affects or indicates degradation in the safety, security, environmental or health protection performance or operation of a facility. **(RCS)**

activity median aerodynamic diameter: The diameter of a sphere having a density of 1 g cm^{-3} with the same terminal settling velocity in air as that of the aerosol particle whose activity is the median for the entire aerosol. **(Internal Dosimetry Chapter of the IG)**

air sampling: A form of air monitoring in which an air sample is collected and analyzed at a later time, sometimes referred to as retrospective air monitoring.

air monitoring: Actions to detect and quantify airborne radiological conditions by the collection of an air sample and the subsequent analysis either in real-time or off line laboratory analysis of the amount and type of radioactive material present in the workplace atmosphere. **(Internal Dosimetry Chapter of the IG)**

airborne radioactive material: Radioactive material in any chemical or physical form that is dissolved, mixed, suspended, or otherwise entrained in air.

alarm set point: The count rate at which a continuous air monitor will alarm, usually set to correspond to a specific airborne radioactive material concentration by calculating the sample medium buildup rate.

ambient air: The general air in the area of interest (e.g., the general room atmosphere) as distinct from a specific stream or volume of air that may have different properties.

breathing zone air monitoring: Actions conducted to detect and quantify the radiological conditions of air from the general volume of air breathed by the worker, usually at a height of 1 to 2 meters. See *personal air monitoring*. **(Workplace Air Monitoring Chapter of the IG)**

continuous air monitor (CAM): An instrument that continuously samples and measures the levels of airborne radioactive materials on a “real-time” basis and has alarm capabilities at preset levels.

decision level (*DL, L_C*): The amount of a count or a count rate or the final instrument measurement of a quantity of analyte at or above which a decision is made that the analyte is definitely present. **(ANSI, 2011b)**

decontamination: The process of removing radioactive contamination and materials from personnel, equipment or areas. **(RCS)**

detector: A device or component that produces a measurable response to ionizing radiation. **(Portable Instrument Calibration Chapter of the IG)**

DOELAP: The Department of Energy Laboratory Accreditation Program for personnel dosimetry. **(RCS)**

dose: The amount of energy deposited in body tissue due to radiation exposure. **(RCS)**

exposure: The general condition of being subjected to ionizing radiation, such as by exposure to ionizing radiation from external sources or to ionizing radiation sources inside the body. In this document, exposure does not refer to the radiological physics concept of charge liberated per unit mass of air. **(Internal Dosimetry Chapter of the IG)**

fissionable materials: A nuclide capable of sustaining a neutron - induced fission chain reaction (e.g., uranium-233, uranium-235, plutonium-238, plutonium 239, plutonium -241, neptunium-237, americium- 241 and curium-244) **(10 CFR 830)**.

fixed contamination: Any area with detectable removable contamination less than the removable contamination values of Appendix D of 10 CFR 835 and fixed contamination at levels that exceed the total contamination values of Appendix D of 10 CFR 835. **(Posting and Labeling Chapter of the IG)**

fixed-location sampler: An air sampler located at a fixed location in the workplace.

grab sampling: A single sample removed from the workplace air over a short time interval, typically less than one hour.

hazardous waste: Because of its quantity, concentration, and physical, chemical, or infectious characteristics, hazardous waste may cause or significantly contribute to an increase in mortality, or an increase in serious irreversible or incapacitating reversible illness; it may pose a potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed. **(DOE/S-0101)**

high-efficiency particulate air (HEPA) filter: Throwaway extended pleated medium dry-type filter with 1) a rigid casing enclosing the full depth of the pleats, 2) a minimum particle removal efficiency of 99.97% for thermally generated monodisperse di-octyl phlalate smoke particles with a diameter of 0.3 μm, and 3) a maximum pressure drop of 1.0 in. w.g. when clean and operated at its rated airflow capacity. **(RCS)**

HLW: High-level waste (HLW) is the material that remains following the reprocessing of spent nuclear fuel and irradiated targets from reactors. The HLW is highly radioactive and generates heat on its own. Some of its elements will remain radioactive for thousands of years. Because of this, HLW shall be managed very carefully and all handling shall be performed from behind heavy protective shielding. **(DOE/S-0101)**

intake: The amount of radionuclide taken into the body by inhalation, absorption through intact skin, injection, ingestion or through wounds. Depending on the radionuclide involved, intakes may be reported in mass (e.g., μg, mg) or activity (e.g., μCi, Bq) units. **(Internal Dosimetry Chapter of the IG)**

LLW: Low-level waste (LLW) is any radioactive waste that is not HLW, spent nuclear fuel, TRU waste, or uranium mill tailings. The LLW is typically contaminated with small amounts of radioactivity dispensed in large amounts of material. The LLW is generated in every process involving radioactive materials in the DOE including decontamination and decommissioning projects. **(DOE/S-0101)**

minimum detectable amount/activity (MDA): The smallest amount (activity or mass) of an analyte in a sample that will be detected with a probability β of non-detection (Type II error) while accepting a probability α of erroneously deciding that a positive (non-zero) quantity of analyte is present in an appropriate blank sample (Type I error). **(ANSI N13.30-2011)**

MW: Mixed waste (MW) is waste that contains both radioactive and hazardous wastes. Any of the types of radioactive waste described can be a mixed waste if it contains any hazardous wastes. In fact, all of DOE's HLW is mixed waste because of the chemicals used to reprocess the fuel that resulted in the generation of the material or because it is suspected to contain hazardous materials. **(DOE/S-0101)**

personal air monitoring: The monitoring of air for radioactive particles in the immediate vicinity of an individual radiation worker's nose and mouth, usually by a portable sampling pump and collection tube (such as a lapel sampler) worn on the body. Personal air monitoring is a special case of breathing zone air monitoring. **(Workplace Air Monitoring Chapter of the IG)**

portable air sampler: An air sampler designed to be moved from area to area.

radiation-generating device (RDG): The collective term for devices which produce ionizing radiation, sealed sources which emit ionizing radiation, small particle accelerators used for single purpose applications which produce ionizing radiation (e.g., radiography), and electron-generating devices that produce x-rays incidentally. **(Radiation-Generating Devices Chapter of the IG)**

radioactive material: For the purposes of the standard, radioactive material includes any material, equipment or system component determined to be contaminated or suspected of being contaminated. Radioactive material also includes activated material, sealed and unsealed sources, and material that emits radiation. **(RCS)**

radiological work permit (RWP): The permit that identifies radiological conditions, establishes worker protection and monitoring requirements, and contains specific approvals for radiological work activities. The Radiological Work Permit serves as an administrative process for planning and controlling radiological work and informing the worker of the radiological conditions. **(RCS)**

radiological protection organization: A contractor organization responsible for radiation protection activities within contractor facilities. This organization is independent of the line organizational element responsible for production, operation, or research activities and should report to the contractor senior site executive. **(Sealed Source Chapter of the IG)**

real-time air monitoring: Collection and real-time analysis of the workplace atmosphere using continuous air monitors (CAMs).

refresher training: The training scheduled on the alternate year when full retraining is not completed for Radiological Worker I and Radiological Worker II personnel. **(RCS)**

removable contamination: Radioactive material that can be removed from surfaces by nondestructive means, such as casual contact, wiping, brushing or washing. **(RCS)**

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representative air sampling: The sampling of airborne radioactive material in a manner such that the sample collected closely approximates both the amount of activity and the physical and chemical properties (e.g., particle size and solubility) of the aerosol to which the workers may be exposed.

sanitary waste: Sanitary waste is waste that is neither hazardous nor radioactive. **(DOE/S-0101)**

source-specific air sampling: Collection of an air sample near an actual or likely release point in a work area using fixed-location samplers or portable air samplers.

survey: An evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal, or presence of radioactive material or other sources of radiation. When appropriate, such an evaluation includes a physical survey of the location of radioactive material and measurements or calculations of levels of radiation, or concentrations or quantities of radioactive material present.

TRU: Transuranic (TRU) waste refers to waste materials containing elements with atomic numbers greater than 92. These elements are generally alpha-emitting radionuclides that decay slowly. The TRU waste contains a concentration of these elements greater than 100 nCi/g. The TRU waste is not as intensely radioactive as HLW. The TRU waste also decays slowly, requiring long-term isolation. **(DOE/S-0101)**

workplace monitoring: The measurement of radioactive material and/or direct radiation levels in areas that could be routinely occupied by workers.

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CONCLUDING MATERIAL

Review Activities:

DOE
Ops Offices

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EM
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SC
NV
SA
OR
LM
RL
NE
SR
NS
PR

Area/Site Offices
Ames
Argonne
Berkeley
Brookhaven
Carlsbad
Fermi
Kansas City
Los Alamos
Oak Ridge Site Office
Princeton
SLAC
Thomas Jefferson
West Valley
Y-12

National Laboratories
Ames
ANL
BNL
FNAL
LBNL
ORNL
PPPL
SLAC
TJNAL

Preparing Activity:

DOE AU-11