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DOE STANDARD

CRITERIA FOR SAFE STORAGE OF PLUTONIUM METALS AND OXIDES

U.S. Department of Energy
Washington, D.C. 20585

AREA PACK

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Foreword

This Department of Energy standard is approved for use by all DOE components and their contractors.

Plutonium storage practices at Department of Energy (DOE) facilities evolved over decades during which the objectives of Department programs were to support nuclear weapons development and production. These storage practices reflected a desire to primarily maintain plutonium in metal form for prompt recycling into weapon components. Weapon-grade plutonium generally was considered to be either "in-process" or "in-use". Prevailing procedures and safety requirements addressed only short-term storage. The end of the Cold War and the new arms control agreements are leading to the retirement of large numbers of nuclear weapons resulting in an excess of plutonium that will require management.

This standard establishes safety criteria for safe storage of plutonium metals and plutonium oxides at DOE facilities. Plutonium materials packaged to meet these criteria should not need subsequent repackaging to ensure safe storage for at least 50 years or until final disposition.

TABLE OF CONTENTS

	Page
Foreword.....	i
1.0 Purpose and Scope	1
2.0 Definitions and Acronyms	3
3.0 Relevant Orders, Standards, and Documents	7
3.1 Federal Regulations	7
3.2 Department of Energy Documents.....	7
3.3 Nuclear Regulatory Commission Documents.....	8
3.4 Non-Government Publications.....	8
4.0 Safe Storage Criteria.....	9
4.1 Material Form	9
4.2 Packaging	10
4.3 Inspection and Surveillance for Safety	14
4.4 Documentation	15
4.5 Quality Assurance/Control Requirements	15
Appendix A. Bases for Plutonium Storage Criteria.....	A1

1.0 PURPOSE AND SCOPE

1.1 Purpose

This standard provides for safe storage of plutonium metals and oxides for at least 50 years or until final disposition. To meet the criteria, DOE facilities will have to store stable plutonium-bearing forms in containers designed to maintain their integrity both under normal conditions and during postulated accident conditions.

1.2 Scope

This standard applies to the safe storage of plutonium metals, selected alloys (e.g., gallium and aluminum alloys), and stabilized oxides that contain a minimum of 50 weight-percent plutonium. It does not apply to the storage of plutonium-bearing liquids, process residues, waste, sealed weapon components, or material containing more than three weight-percent ^{238}Pu . Requirements for a plutonium storage facility, and safeguards and security considerations are not stressed in these criteria, since they are addressed in detail by other DOE orders.

2.0 DEFINITIONS AND ACRONYMS

Acceptable - Conforming with safety requirements, directives, or regulations.

Alloy - A condensed substance composed of two or more metallic elements formed by melting and intercomponent dissolution when molten. Only those plutonium alloys that are solids at storage temperatures are acceptable for storage.

ANSI - American National Standards Institute.

ASME - American Society of Mechanical Engineers.

Barrier - A confinement that prevents the dispersion of stored material.

Boundary Container - A sealed container that provides a structurally acceptable barrier for containing plutonium-bearing materials in storage, contains no organic materials, and is dimensionally compatible with the primary containment vessel. (See Figure 1.)

Data Base - A large collection of data in a computer, organized so that it can be expanded, updated, and retrieved rapidly for various uses.

DOE - United States Department of Energy.

Enclosure - A physical structure that provides a barrier between the internally contaminated package and the worker, facility, and environment.

Handling Enclosure - A glovebox line or similar equipment that isolates plutonium-bearing materials from the worker's environment while allowing the material to be handled or processed.

Inert Gas - A non-reactive gas or combination of gases appropriate to the material being stored that will not support corrosion of the container or oxidation of its contents.

In-Line - Something located inside a plutonium handling enclosure (e.g., glove box or "hot" storage vault). When plutonium is stored "in-line", the enclosure provides one barrier for storage.

In-Process, In-Use Material - Material that is integral to the continuing manufacture or recycle operations of the nuclear weapons complex and may not be considered as excess material for storage.

Leak-Tight - A leakage rate that complies with ANSI N14.5-1987, which is less than or equal to 1×10^{-7} std cm³/s (standard cubic centimeters of gas per second) across a pressure gradient of 1.0 atmosphere. This rate is equivalent to the leakage of 4×10^{-12} moles of air or helium per second.

Loss on Ignition (LOI) - Percentage of mass loss measured when a representative sample of processed (e.g., thermally stabilized) plutonium-bearing oxide is heated at a specified temperature for the time period required (as demonstrated by certification procedures) to remove residual moisture and other volatile species from the sample. LOI

test can be accomplished by heating the sample in an oxidizing atmosphere to a temperature of 1,000°C (1,832°F) for at least 1 hour.

Material Container - The container that is in contact with the plutonium material being stored. (See Figure 1.) This may be either the boundary container, or a container that resides inside of a boundary container. If structurally adequate and sealed, the material container provides one barrier.

MC&A - Material Control and Accountability.

NFPA - National Fire Protection Association.

NUREG - Nuclear Regulatory Commission-produced reference document.

Out-of-Line - Something located outside of a plutonium handling enclosure.

Packaging - The assembly of materials and components in compliance with storage/shipment requirements.

Plutonium Oxide - Plutonium-bearing oxides with minor concentrations of non-volatile inorganic compounds that remain after thermal processing to remove adsorbed species.

Primary Containment Vessel - The outer-most sealed container intended for safe storage. When used as the outer-most container for storage, it would also be used for shipping.

Process - To extract, separate, purify, or fabricate a material by physical, chemical, or mechanical means.

Quality Assurance (QA) - All planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service.

Quality Control (QC) - Those quality assurance activities that provide a means to control and measure the characteristics of a structure, system, or component to established requirements.

Residue - Process-generated plutonium-bearing materials not classified as storable metal or stabilized oxide that contain a non-discardable quantity of plutonium.

Sealed - Sealed means that a container has been closed (e.g., welded) and certified to be leak-tight in accordance with ANSI N14.5-1987 standard.

Shall, Should and May - "Shall" denotes that something is required. "Should" denotes that something is recommended. "May" denotes that something is permitted.

Specific Surface Area - The ratio of the geometric surface area of a material to its mass in units of cm²/g.

Standard Cubic Centimeter of Gas - The quantity (moles) of gas in one cubic centimeter of volume at 1 atmosphere pressure and 25°C (298 K).

Storage - Any method for safely maintaining items in a retrievable form for subsequent use or disposition.

Storage Facility - The building structure and other confinement systems that house the storage containers.

Storage Package - A configuration of nested containers including package content.

Thermally Stabilize - A process that exposes a plutonium-bearing material to a high temperature and air, or other oxidizing atmosphere for the period of time required to convert reactive constituents to oxide while reducing the amount of adsorbed water and other chemical species to a level compliant with the LOI specification for storage. Thermal stabilization can be accomplished by heating to a recommended temperature of 950°C (1,742°F) for at least one hour.

UCID - University of California Informal Document.

3.0 RELEVANT ORDERS, STANDARDS, AND DOCUMENTS

3.1 Federal Regulations

The following Federal regulations are referenced in this technical standard.

10 CFR 71, Packaging and Transportation of Radioactive Material.

49 CFR 173, General Requirements for Shipments and Packagings.

49 CFR 178, Specifications for Packagings.

Copies of Federal regulations are available from the Government Printing Office (GPO), Superintendent of Documents, Mail Stop: SSOP, Washington, DC 20402-9329

3.2 Department of Energy Documents

The following DOE Orders and reports are referenced in this technical standard.

DOE 5480.3, Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Wastes, July 1985.

DOE 5480.7A, Fire Protection, February 1993.

DOE 5480.11, Radiation Protection for Occupational Workers, June 1992.

DOE 5480.23, Nuclear Safety Analysis Reports, April 1992.

DOE 5480.24, Nuclear Criticality Safety, August 1992.

DOE 5633.4, Nuclear Materials Transactions: Documentation and Reporting, February 1988.

DOE 5660.1B, Management of Nuclear Materials, May 1994.

DOE 5700.6C, Quality Assurance, August 1991.

DOE 6430.1A, General Design Criteria, April 1989.

DOE/EH-0256T, US Department of Energy Radiological Control Manual, Rev. 1, April 1994.

DOE/DP-0123T, Assessment of Plutonium Storage Safety Issues at Department of Energy Facilities, January 1994.

Copies of DOE Orders are available from:

U.S. Department of Energy
AD-631/FORS
Washington, DC 20585
(202)586-9642

3.3 Nuclear Regulatory Commission (NRC) Documents

The following NRC documents are referenced in this technical standard.

NUREG/CR-3019, Recommended Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Materials, March 1984.

NUREG/CR-3854, Fabrication Criteria for Shipping Containers, March 1985.

NRC Inspection and Enforcement Manual, Inspection Procedures 61700, 61701 and 61725.

Copies of NRC documents are available from:

U.S. Nuclear Regulatory Commission
Public Document Room
2120 L Street, N.W.
Lower Level
Washington, DC 20555-1000

3.4 Non-Government Publications

The following non-government documents are referenced in this technical standard.

ANSI N14.5-1987, Standard for Radioactive Materials - Leakage Tests on Packages for Shipment, American National Standards Institute, Inc., New York, NY.

ASME Boiler and Pressure Vessel Code, Section VIII, 1992, The American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, N.Y., NY.

DPSPU-83-124-1, Safety Analysis Report-Packages, USA/9968/B()F(DOE-SR) (Packaging of Fissile and Other Radioactive Material), June 1984. U.S. Department of Energy, Savannah River Operations Office, P.O. Box A, Aiken, SC.

NFPA 101, Life Safety Code, 1994, Section 7.

PE-GR-002, Design and Status of the SAFKEG 2863B, October 1992. Los Alamos National Laboratory, Los Alamos, NM.

UCID-21218, Packaging Review Guide for Reviewing Safety Analysis Reports for Packaging, October 1988, Lawrence Livermore National Laboratory, Livermore, CA.

4.0 SAFE STORAGE CRITERIA

The following safety criteria are established to minimize hazards to workers, the public, and the environment associated with the storage of plutonium metals and oxides. Bases for the criteria are provided in Appendix A, and are discussed in DOE/DP-123T, "Assessment of Plutonium Storage Safety Issues at Department of Energy Facilities," January 1994.

4.1 Material Form

A. General

- 1) The stored materials shall be in solid metal or conditioned oxide (powder or compacted) forms and contain a minimum of 50 weight-percent plutonium.
- 2) The stored forms shall be readily retrievable from the containers.

B. Material Quantity

The quantity of stored plutonium per storage package or primary containment vessel shall have a thermal output of less than 30 Watts.

The quantity of stored plutonium as metal per primary containment vessel should be as close as possible to, but shall not exceed, 4.50 kg (9.90 lb.). Actual operating limits shall be facility-specific considering criticality, radiation, and heat output constraints. The steady-state plutonium metal temperature shall not exceed 100°C (212 °F).

The quantity of stored plutonium oxides per primary containment vessel should be as close as possible to, but shall not exceed, 5.10 kg (11.20 lb.). Actual operating limits shall be facility-specific considering criticality, radiation, and heat output constraints.

C. Metal

- 1) Stored metal pieces shall have thicknesses greater than 1.0 mm (0.04 in.) or have specific surface areas less than 1.0 cm²/g (71 in²/lb.). Metal pieces with greater surfaces shall be converted to an oxide form. (See Appendix A)
- 2) Plutonium metal shall be free of loose oxide.

D. Oxides

- 1) Plutonium oxides shall be thermally stabilized to less than 0.5% loss on ignition (LOI), and retain this characteristic through final packaging.

4.2 Packaging

For safe plutonium storage, the package shall have a minimum of two barriers.

For in-line storage, the plutonium metal or oxide shall be in a container that meets the requirements for a boundary container. The second barrier will be provided by the plutonium handling enclosure.

For out-of-line storage, the plutonium metal or oxide shall be either :

- sealed in a material container nested in a boundary container (until a primary containment vessel can be used); or
- sealed in a boundary container nested in a primary containment vessel.

The inner-most sealed container shall be filled with an inert gas or a glovebox atmosphere that will not create a need for restabilizing the material. Design of the containers shall allow for inspection and surveillance. The contents of each container shall be identified on the container's exterior and noted in the data base referred to in Section 4.4. Markings shall be of a permanent nature such as etched, or engraved.

4.2.1 Material Container

A material container shall be free of organic materials such as plastics, elastomeric gaskets, and organic coatings.

A material container may be acceptable as the boundary container, if it meets the requirements in Section 4.2.2.

4.2.2 Boundary Container

A boundary container shall meet the following requirements:

A. Dimensional Requirements

Sized to fit into the primary containment vessel with allowances made for internal packing and clearances for welding the primary containment vessel closed. The following are the recommended boundary container dimensions:

- Maximum outer diameter of 12.5 cm (4.9 in.)
- Maximum external height of 25.4 cm (10.0 in.); with a hemispherical bottom, the maximum height can be 27.9 cm (11.0 in.)

B. Containment Requirements

Sealed and tested after initial fill for leak-tightness as defined in ANSI N14.5.

C. Structural Requirements

- 1) Shall be fabricated of material that will be corrosion-resistant in environmental conditions expected in a plutonium storage facility.
- 2) The loaded boundary container shall remain leak-tight as defined by ANSI N14.5 after the following one-time, abnormal occurrences:
 - 122 cm (4 ft.) drop onto a flat, essentially unyielding, horizontal surface.
 - 61 cm (2 ft.) crush in which boundary containers collide.
 - Compression weight of five (5) boundary containers.

D. Pressure Requirements

Shall be proof-tested to 1.5 times¹ the theoretical maximum internal pressure (See Appendix A, Section 4.2.3.F).

E. Container Packing Requirements

Shall be free of organic materials such as plastic bags, organic coatings, and elastomeric gaskets.

4.2.3 Primary Containment Vessel

The primary containment vessel shall meet the following requirements:

A. General Requirements

- 1) Shall be designed for dual use, for safe storage and as the primary containment vessel for shipping.
- 2) Shall be compatible with the shipping envelope as defined by the following:
 - 10 CFR 71, Packaging and Transportation of Radioactive Material.
 - 49 CFR 173, General Requirements for Shipments and Packagings.
 - 49 CFR 178, Specifications for Packagings.

¹ASME Boiler & Pressure Vessel Code 1992, Section VIII, Division 1, Part UG-99.

DOE 5480.3, Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances and Hazardous Wastes.

- 3) The space between the boundary container and the primary containment vessel shall be free of removable contamination as defined by *DOE Radiological Control Manual*, DOE/EH-0256T.
- 4) Shall be designed for leak testing and gas sampling.
- 5) Vessel design shall be compatible with automated handling equipment.

B. Dimensional Requirements

The dimensional requirements for a primary containment vessel are based on the size limits set by an existing licensed secondary shipping container. The dimensional requirements are as follows:

- 1) Maximum inside diameter of 13.3 cm (5-1/4 in.).
- 2) Maximum outside diameter 15.2 cm (6 in.).
- 3) Maximum external height of 43.2 cm (17 in.) for a vessel configured for shipping.

C. Containment Requirements

- 1) Provisions shall be provided for purge and backfill of the containment vessel.
- 2) The vessel shall be resealable to original integrity after a gas sampling operation is complete.
- 3) Nondestructive examination of the resealed vessel shall be possible to establish the integrity of resealed vessel.
- 4) The sealed vessel shall be leak-tight as defined by ANSI N14.5.

D. Structural Requirements

- 1) The primary containment vessel shall meet the following requirements:
 - ASME Boiler and Pressure Vessel Code as specified by UCID-21218 - Rev.1, Packaging Review Guide for Reviewing Safety Analysis Reports for Packagings, October 1988.
 - NUREG/CR-3019, Recommended Welding Criteria for Use in The Fabrication of Shipping Containers for Radioactive Materials.
 - NUREG/CR-3854, Fabrication Criteria for Shipping Containers.

- 2) Shall be designed for reuse.
- 3) The vessel's minimum design life shall be 50 years with no required routine maintenance.
- 4) Shall be fabricated of materials that would provide a corrosion-resistant barrier in environmental conditions expected in a plutonium storage facility.
- 5) Shall meet dimensional and containment requirements of paragraphs B and C above after the following anticipated handling occurrences²:
 - 122 cm (4 ft.) drop onto a flat, essentially unyielding, horizontal surface.
 - 61 cm (2 ft.) crush in which primary containment vessels collide.
 - Handling shock.
 - Compression weight of five (5) primary containment vessels.
- 6) A loaded vessel shall remain leak-tight as defined by ANSI N14.5 after the following one-time, abnormal occurrences²:
 - 9 meter (30 ft.) free drop onto a flat, essentially unyielding, horizontal surface.
 - 9 meter (30 ft.) crush in which primary containment vessels collide.
 - Vehicle crush.
 - Puncture.

E. Pressure Requirements

- 1) Primary containment vessels shall be designed to withstand 5,175 kPa (750 psig) internal pressure at 204°C (400°F).
- 2) Primary containment vessels shall be designed to withstand 147 kPa (21 psig) external pressure.

F. Packing Requirements

- 1) Packing material within the primary containment vessel shall be noncombustible as defined in NFPA, Life Safety Code.
- 2) Packing material inside the primary containment vessel shall be inorganic material (without plastics).
- 3) Steady-state plutonium metal temperature shall not exceed 100°C (212 °F).

²Handling and abnormal occurrence test requirements for the primary containment vessel are under development by Sandia National Laboratory, Albuquerque, NM.

- 4) Primary containment vessels shall be capable of holding a boundary container with 4.50 kg (9.90 lb.) of plutonium metal, or 5.10 kg (11.2 lb.) of plutonium oxide, with a minimum required free volume of 2.5 liters (153 in³) remaining to prevent container pressure from exceeding the design limit.

4.3 Inspection and Surveillance for Safety

- A. Inspection and surveillance procedures shall identify:
 - 1) Prerequisites.
 - 2) Acceptance criteria.
 - 3) Specific instructions to ensure that rejected items are repackaged and reinspected for acceptance after identification.
 - 4) Frequency of inspection.
- B. Inspections and surveillances for safety shall be performed only by qualified workers.
- C. Formal methods and responsibilities shall be documented and maintained for independent review and evaluation.
- D. Inspection of packages should be integrated with other required inspections such as Material Control and Accountability (MC&A).
- E. Surveillance testing frequency, container sample size, and container selection shall be established using a statistical approach to ensure that package integrity is maintained with a high degree of confidence. Testing frequency shall be adjusted to account for surveillance failures identified.
- F. Inspections shall be performed on containers within 30 days following container closure.
- G. Baseline package weight and boundary container (or sealed material container) dimensions shall be recorded as references for checking weight changes and inner container distortion.
- H. Surveillance of containers shall be performed to determine container integrity and condition of the contents. Tests could be either intrusive or non-intrusive.
- I. Actions taken for inspection and surveillance failures shall be in accordance with approved procedures and DOE reporting requirements.

4.4 Documentation

- A. A schedule shall be maintained of safety and accountability surveillance testing.
- B. A data base shall be maintained to serve as a master list of relevant information about stored plutonium materials and containers. For completeness, MC&A documentation shall be coordinated with the data base.
- C. The data base shall contain as a minimum:
 - 1) Identification of the following material characteristics:
 - Chemical form and isotopic content
 - Quantity (mass)
 - Source of stored material (facility that generated the material)
 - Specific processing condition(s)
 - LOI test results and conditions of test
 - Backfill gas composition and pressure on sealing
 - Package configuration (material container and/or boundary container)
 - Date and condition of packaging
 - Initial radiation field (gamma and neutron at contact and 30 cm)
 - Surveillance results
 - Other information relative to the contents;
 - 2) Documentation of the inspection tests performed, names of individuals performing inspections, and the dates of inspections,
 - 3) Records of safety inspections, and
 - 4) Locations of stored materials.

4.5 Quality Assurance/Control Requirements

- A. All personnel participating in essential processes and procedures shall be trained and certified for their areas of involvement.
- B. Materials used in the fabrication and sealing of containers shall satisfy all specifications necessary to comply with the requirements of these criteria.
- C. Procedures and processes that are essential for assuring compliance with these criteria shall be covered by Quality Assurance (QA) per DOE 5700.6C and Quality Control (QC) Procedures.
- D. Essential procedures and processes covered by QA and QC requirements shall include (but will not be limited to):
 - 1) LOI procedure used for oxide certification,

- 2) Sealing (e.g., welding) procedures used in container fabrication and closure,
- 3) Leak testing procedures used for certifying that containers are leak-tight,
- 4) Surveillance procedures, and
- 5) Data base procedures and characterization parameters addressed in Section 4.4.C.

**Figure 1. Packaging Configurations for Safe Storage
Using a Primary Containment Vessel**

Option 1

Plutonium is packaged in a material container. The material container (or containers) does not meet the criteria for boundary container. Thus, the material container(s) is sealed in a boundary container. The boundary container is then stored in a primary containment vessel.

Option 2

Plutonium is packaged in a material container. The material container package meets the criteria for a boundary container. Thus, no additional boundary container is needed. The material container (or containers) is stored directly in a primary containment vessel.

- Barrier provided by the primary containment vessel
- Barrier provided by a boundary container
- Barrier provided by a material container that does not qualify as a boundary container

APPENDIX A

BASES FOR PLUTONIUM STORAGE CRITERIA

The paragraphs in this Appendix briefly provide the bases for the paragraphs in the body of this Standard. For this reason, the numbering of the sections in the Appendix corresponds to that in the body of the Standard.

1.0 PURPOSE AND SCOPE

This standard establishes safety criteria for safe storage of plutonium metals and plutonium oxides at DOE facilities. Plutonium materials packaged to meet these criteria should not need subsequent repackaging to ensure safe storage for at least 50 years or until final disposition.

2.0 DEFINITIONS AND ACRONYMS

No Basis Provided.

3.0 RELEVANT ORDERS, STANDARDS, AND DOCUMENTS

No Basis Provided.

4.0 SAFE STORAGE CRITERIA

4.1 Material Form

A. General

Metals and stabilized oxides can be stored safely under prescribed conditions. This is discussed in DOE/DP-0123T, "Assessment of Plutonium Storage Safety Issues at Department of Energy Facilities," January 1994.

Ultimate disposition of the stored plutonium is currently undefined. The plutonium materials might be used in civilian applications, such as for mixed oxide (MOX) reactor fuel, or as a metallic constituent in the fuel for a liquid metal reactor (LMR). The safe storage forms and package should not hinder future disposition options.

This standard applies to the safe storage of plutonium metals, selected alloys (e.g., gallium and aluminum alloys), and stabilized oxides that contain a minimum of 50 weight-percent plutonium. It does not apply to plutonium-bearing liquids, residues, waste, sealed weapon components, or material containing more than three weight-percent ^{238}Pu .

Typical plutonium isotopic compositions (by weight-percent) for various grades of plutonium are as follows:

Isotope (weight %)	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
Weapons Grade	<0.05	93.6	6.0	0.4	<0.05
Fuel Grade	0.1	86.1	12	1.6	0.2
Power Grade	1.0	62	22	12	3.0

B. Material Quantity

The permitted quantity of plutonium per package depends on isotopic composition which affects heat output, radiation levels, and criticality constraints. Shipping

requirements limit the thermal output to a maximum of 30 Watts per package (See DPSPU-83-124-1). The maximum fissile unit for an isolated sphere of pure ^{239}Pu that is water-reflected and has a 0.05 margin in K_{eff} is calculated at 4.53 kg (9.97 lb.). The quantity of plutonium packed into each container should be as close as possible to the facility specific limits to minimize the total number of packages generated.

C. Metal

The specified thickness and surface area are based on the potential for experiencing pyrophoricity. This is discussed in the Assessment Report, Section II.F, "Pyrophoricity," and Section V.B.1, "Chemical Reactivity." (See DOE/DP-0123T). Only loose oxides are considered to be detrimental. An adherent oxide layer on stored metal is beneficial because it tends to retard further oxidation. Prior to repackaging plutonium metal, loose oxide must be removed from the metal by brushing. The Assessment Report, Section II.B, describes the reactions of plutonium metal with moisture, resulting in its degradation and creating pyrophoric hydrides (See Section II.C of the Assessment Report, DOE/DP-0123T).

D. Oxides

Plutonium dioxide powders can have a high surface area which could adsorb up to 8% of their weight as water. The hazard concern associated with adsorbed water is ultimate pressurization of a sealed oxide container over a prolonged period through any of several radiolytic and chemical processes. Sections II.B and VI of the Assessment Report respectively discuss the removal of adsorbed water from oxides and the proposed criteria for minimizing moisture contents during oxide and metal handling and storage. Appendices C and D of this Assessment Report provide calculations for determining pressure rise and heat generation.

4.2 Packaging

The design goal for the storage package is that it should be maintenance free, and be qualified for shipping offsite without additional repackaging.

4.2.1 Material Container No Basis Provided.

4.2.2 Boundary Container

The boundary container serves two purposes. First, it enables the assembly and welding of the outer primary containment vessel to be performed with minimal potential for spreading radiological contamination. Second, since the surfaces between the primary containment vessel and the boundary container will be free of transferable contamination at the time of packaging, subsequent detection of radioactivity during gas sampling can be used as an indicator of boundary container failure.

The dimensional limits of the boundary container are based on the primary containment vessel design. The primary containment vessel will be fabricated from 5 inch schedule 40 pipe that has a nominal inner diameter of 12.7 cm (5 in.).

The requirement for a corrosion resistant boundary container is based on operational experience and current evaluations of technology for storing stable plutonium-bearing materials. Ductile material should be used for boundary containers. The suggested container material is 304 L stainless steel. This material has good resistance properties to stress corrosion. The proof-testing of the boundary container at 1.5 times the theoretical maximum internal pressure is based on ASME Boiler and Pressure Vessel Code 1992, Section VIII, Division 1, Part UG-99.

The Assessment Report, Section II.D (See DOE/DP-123T), describes the radiolytic effects with plastics, hydrogenous compounds, and organic materials in the storage of plutonium. Prolonged plutonium storage requires exclusion of such materials from the containers.

4.2.3 Primary Containment Vessel

A. General Requirements

Dual use of the storage container as a primary containment vessel for shipping will reduce costs and avoid the additional personnel exposure, operational risk, and waste generation associated with repackaging material for shipping.

For the storage container to also be the primary containment vessel for shipping plutonium offsite, it will have to meet packaging and transportation requirements. Federal regulations 10 CFR 71 and 49 CFR 173 pertain to transportation of radioactive materials. DOE 5480.3 sets out additional DOE requirements for transportation of radioactive material.

B. Dimensional Requirements

The maximum criticality-safe diameter for fissile plutonium is generally regarded as 13.3 cm (5.25 in.). This diameter is the maximum allowed for DOT Spec. 2R inner containment vessel for fissile shipments (See 49 CFR 178.354-3b).

The maximum dimensions noted for the primary containment vessel are the limiting vessel dimensions for fitting inside the secondary containment vessel of existing shipping packages, e.g., SAFKEG (See PE-GR-002) and 9968 (See DPSPU-83-124-1).

C. Containment Requirements

If a vessel has been in storage, gas sampling is required prior to shipping. Gas composition and primary containment vessel pressure are indicators for detecting leaks. Statistical gas sampling also may be required during storage for container integrity evaluations. Original vessel integrity must be ensured for transportation and continued safe storage.

Each vessel design must account for nondestructive examination techniques to ensure that each container can be examined non-destructively and still retain vessel integrity.

ANSI N14.5, Radioactive Materials - Leakage Tests on Packages for Shipment, specifies test methods to demonstrate that shipping packages comply with the

requirements of 10 CFR 71. The acceptable maximum leak rate is 1×10^{-7} std. cc/sec at one atmosphere in air.

Welded closures and ports provide the highest integrity and longest life seals possible. They eliminate gaskets, which are prone to degradation and leakage, and mechanical devices such as bolts or screwed connections that are prone to wear, creep relaxation, seizure, or other mechanical failure.

D. Structural Requirements

The structural requirements are based on the design requirement that this vessel will also serve as the primary containment vessel in a shipping package for offsite transportation in accordance with 10 CFR 71.

The requirement that each primary containment vessel be reusable will result in cost savings and waste reduction.

A vessel design life of less than 50 years would necessitate maintenance or repackaging of the vessel during the anticipated 50-year duration of storage. This could involve significant cost, waste generation, operational risk and personnel exposure.

Operating history shows that currently used containers are subject to corrosion. A corrosion-resistant container would minimize the potential for a breach in confinement and provide good surfaces for decontamination, if needed.

E. Pressure Requirements

The design pressure is based on the specification for 0.5 % maximum loss on ignition test for plutonium oxide. Internal pressure in a sealed container could be generated by several mechanisms including radiolysis products of adsorbed residual water or other contaminants, helium generation by alpha decay of the plutonium, and a temperature of 204°C (400°F) that could result from a major facility fire. These conditions could give a maximum internal pressure of 3,450 kPa (500 psig). The design pressure for the primary containment vessel is set at 5,175 kPa (750 psig) to provide an added margin of safety. ASME Boiler and Pressure Vessel Code 1992, Section VIII, Division 1, Part UG-99, calls for proof-testing at 1.5 times the design pressure.

Federal regulation 10 CFR 71 requires that each primary containment vessel shall be designed for submergence in 15.2 meters (50 ft.) of water. An external pressure of 147 kPa (21 psig) is considered to meet this condition. Each vessel shall be capable of evacuation for back-filling operations resulting in a minimum of 101 kPa (1 atmosphere) of external pressure.

F. Packing Requirements

The storage vault compartments are low fire hazard areas not requiring fire suppression systems. The use of combustible materials in the vault compartments, such as packing materials, will jeopardize the low hazard classification. Combustible loading will be analyzed during the Fire Protection Design Analysis required by DOE 5480.7.

Long-term radiation exposure degrades organic packing materials. The magnitude of this effect depends on the specific material. Radiolysis of organic material can produce combustible or corrosive gases and increase pressure within a sealed storage container. Also, radiation can change the composition of organic materials so that they no longer have the same dimensional, chemical, or physical properties and thereby would not perform the packing function as originally designed.

The transformation temperature of plutonium metal from the α -phase to the β -phase is approximately 117°C (225°F). The metal expands significantly during heating and phase transformation, which is to be avoided. A container must provide sufficient heat dissipation to maintain α -phase plutonium metal below 100°C (212°F) in the shipping and storage environments.

The design limit is based on one and a half times the worst case pressurization scenario, which assumes 100% radiolysis of retained moisture, helium generation for 50 years and 400°F temperature. (Free volume includes space interior to boundary and/or material containers and the interstitial space of the oxide). For 5.10 kg (11.20 lb.) of plutonium oxide, the minimum free volume required is 2.5 liters (153 in³). A primary containment vessel is required to have a free volume of 2.5 liters (153 in³) to provide space for gas generation and to ensure that the design pressure is not exceeded under worst case conditions.

The steady-state storage temperature is determined by the quantity and isotopic distribution of the stored oxide and by the heat transfer characteristics of the storage package. The maximum absolute pressure in a container is the sum of the initial pressure sealed in the container during packaging, the maximum possible pressure generated by radiolysis of adsorbates and the pressure of helium generated by alpha decay of plutonium over time. This pressure (in psia) may be estimated using the following equation:

$$P = P_i + [(LOI)(m)(T)] / [V - (0.0873 m)] + [1.3 \times 10^{-4} (m)(t)(T)] / [V - (0.0873 m)] \quad (1)$$

- P_i is the initial packaging pressure in psia,
- LOI is the maximum allowable loss on ignition value in %,
- m is the mass of packaged oxide in kg,
- T is the maximum anticipated storage temperature in K,
- V is the internal volume of the container in liters, and
- t is the elapsed storage time in years.

The last term, which defines the build-up of helium pressure over time, is formulated for ²³⁹Pu and is applicable to oxides containing the isotopic distribution of weapon-grade plutonium. If the oxide to be stored contains a high concentration of ²³⁸Pu, this term should be evaluated accordingly.

4.3 Inspection and Surveillance for Safety

Items in this section are based on the NRC Inspection and Enforcement Manual, Inspection Procedures 61700, 61701, and 61725.

Inspection and surveillance can be either intrusive or non-intrusive. Non-intrusive testing methods can include the following:

- Radiography to observe oxide growth on plutonium metal, and bulges in the material/boundary container, which would indicate a pressure increase.
- Acoustic resonance spectroscopy to detect pressure changes.
- Weight measurements to detect oxide growth, which would indicate a breach in the container.

Intrusive test methods include gas sampling of the space between the primary containment vessel and the boundary container to detect a leak in the boundary container. Destructive testing of sample containers also may be performed to evaluate the long-term performance of the container design.

4.4 Documentation

Shall be based on sound Records Management practices within the nuclear industry and DOE Orders in the 5600 series (e.g., DOE 5633.4 and 5660.1B)

4.5 Quality Assurance/Control Requirements No Basis Provided.

CONCLUDING MATERIAL

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