APPENDIX A DESCRIPTION, SAFETY FEATURES, AND AREAS OF REVIEW FOR DIFFERENT TYPES OF RADIOACTIVE MATERIAL TRANSPORTATION PACKAGES

A.1 <u>Radiography Packages</u>

A.1.1 Purpose of Package

These packages include radiographic-exposure devices or radiographic-source changers. The purpose of an exposure device is to transport a Type B quantity of special form radioactive material for use as a radiographic gamma source. The purpose of the source-changer device is to transport a radiographic gamma source to and from an exposure device and to exchange radiographic sources with that exposure device.

A.1.2 Description of a Typical Package

A typical packaging used as an exposure device consists of a lead or depleted-uranium shield inside a welded steel or titanium housing. The shield includes a metallic S-shaped tube that houses the source during transport and allows movement of the source into position for radiography. The shield may be fixed in position by retention cups welded to end plates of the housing and by foam between the shield and the housing.

The source is attached to the end of a short metallic cable, or pigtail. A securing lock mechanism is installed at one end of the housing to maintain the source in a fixed position during transport. A safety plug assembly installed at the other end of the S-tube provides a redundant mechanism to prevent movement of the source toward an outlet.

The content of a package used as an exposure device is one radiographic gamma source (e.g., cobalt-60, iridium-192, or selenium-75) in Type B special form.

The package is typically hand-carried by one person using a handle attached to the housing, although some larger radiography cameras that use cobalt-60 are either carried by more than one individual or mounted on wheels.

A typical packaging used as a radiographic source changer is similar to that used as an exposure device. A source changer may contain multiple sources, typically housed in U-shaped tubes. In addition to its function as a transportation package, a source changer is used to move sources either from or to an exposure device. Although the remainder of this appendix specifically addresses exposure devices, the review of a source changer is similar.

A sketch of a typical radiographic exposure device is presented in Figure A.1-1.

A.1.3 Package Safety

<u>Safety Functions</u>

The principal safety function of these packages is to retain the radiographic source and to provide gamma shielding. Containment is provided primarily by the special form source itself. These packages do not contain fissile material.

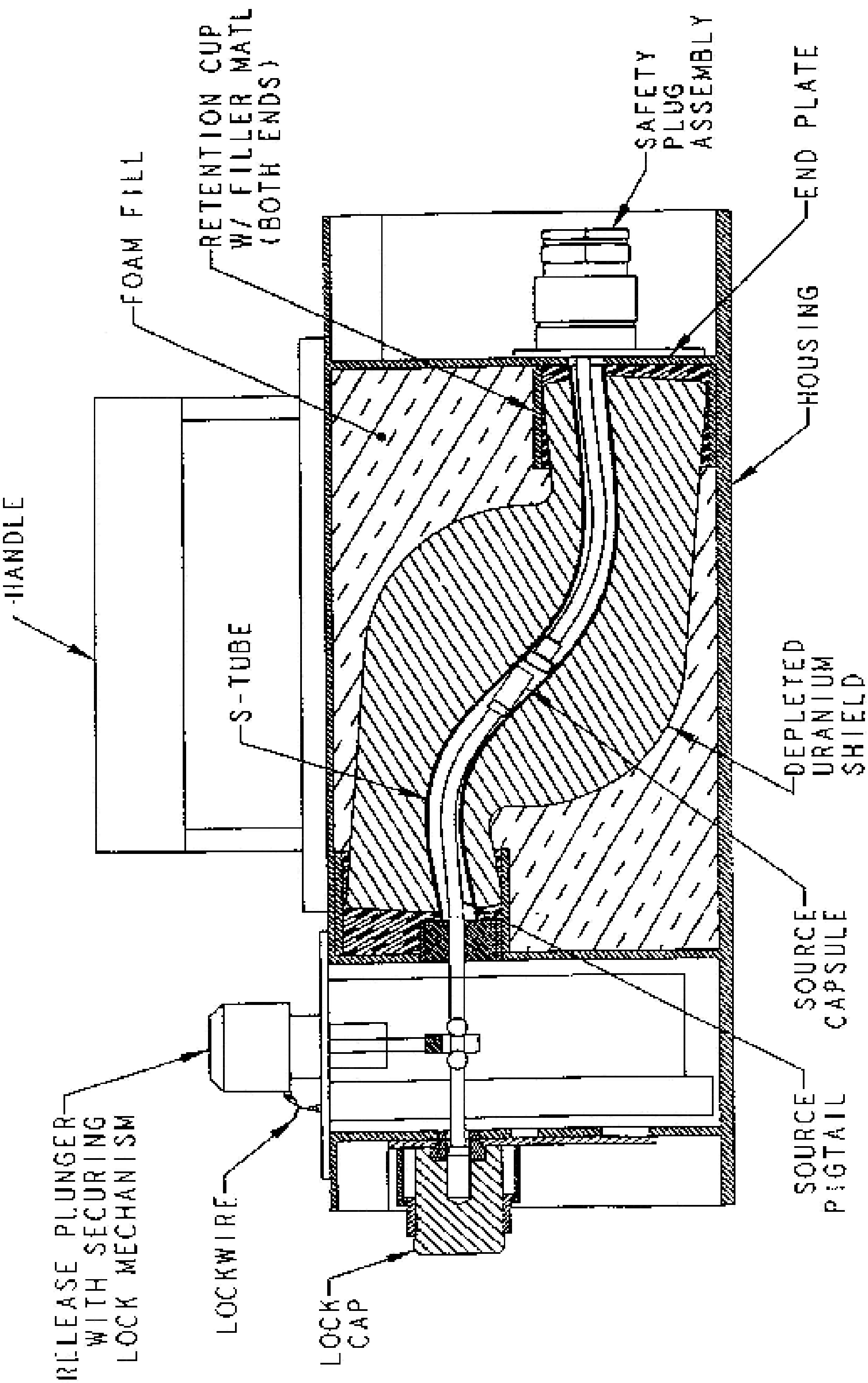

Figure A.1-1 Sketch of a typical radiographic exposure device

Safety Features

- A lead- or depleted-uranium shield, including supplemental shielding, provides gamma shielding.

- A securing lock mechanism positions the source pigtail within the S-tube in the shield during transport to prevent high radiation fields and radiation streaming.

- A safety plug assembly at the opposite end of the tube provides a redundant mechanism to prevent movement of the source.

- The housing, foam, and other structural materials protect the shield and S-tube from damage.

A.1.4 Typical Areas of Review for Package Drawings

- housing features, including dimensions, material, thickness, and welds

- foam material and density

- shield dimensions (including tolerances as appropriate) and material, including supplemental shielding, its maximum weight, dimensions, and method of attachment: Other than the material, total maximum weight, and maximum thickness that may be applied to the primary shield, the specific details of the supplemental shielding are not needed, because it is intended for the maximum strength source to meet the normal conditions dose-rate limit. The drawings should show a general arrangement for using supplemental shielding, if needed to meet normal condition radiation level limits.

- material, wall thickness, and curvature of S- or U-tube

- lock mechanism specifications

- other structural features, including bolts, pins, and retention cups, as applicable

A.1.5 Typical Areas of Safety Review

- The general information review verifies that the contents are restricted to special form and that the source nuclide and maximum allowable activity are specified. Specification of content activity may be expressed as “Bq (output)” [becquerels (output)] or “Ci (output)” [curies (output)] for iridium-192 to denote that the activity is determined from a measurement of the rate of decay or a measurement of the radiation level at a prescribed distance from the source, an example of which is described in Note 1 of American National Standards Institute (ANSI) N432-1980. For all other nuclides, the content activity should be expressed as “Bq” or “Ci.”

- The structural and thermal reviews evaluate the ability of the shield to perform its intended function under normal conditions of transport and hypothetical accident conditions. These reviews address the following:

— damage to the shielding

— misalignment of the S-tube

— damage to the S-tube resulting in exposure of the depleted uranium shield and possible oxidation of the uranium or eutectic reaction between the uranium and other package components

— damage to the securing lock mechanism

— movement of the source relative to the shielding

- The shielding review evaluates the ability of the package to satisfy the maximum allowable external radiation levels under normal conditions of transport and hypothetical accident conditions. Shielding requirements are often demonstrated by measuring the dose rates from a gamma test source that is the same source as the package contents in a prototype package that has undergone the normal conditions of transport and the hypothetical accident conditions tests for the respective radiation level limits. The results of measurement are scaled according to the ratio of the maximum allowed activity of the contents to the activity of the test source. The application includes the results of these measurements and the radiation levels scaled to the package's maximum allowed contents activity. Key issues include the following:

  — ensuring that the locations of the maximum radiation levels on the surface of the package, including near the ends of the S-shaped source tube, and at 1 meter (m) from the surface have been identified

  — determining that the size (active depth and diameter) of the detector is appropriate for providing dose-rate measurements at the regulatory locations (because of the small size of the package, corrections may be needed to account for the size of the detector probe volume) (see ANSI/Health Physics Society (HPS) N43.9-2015 for information about shield-efficiency testing and the International Atomic Energy Agency's (IAEA's) SSG-26, Paragraph 233.5 and Table 1, for information about detector size and measurement-correction factors)

  — examining the design of the source assembly and securing lock mechanism, including pigtail and locking balls (a small movement in source position can result in a significant increase in external radiation levels)

  — verifying that no significant increase in radiation occurs as a result of the tests for normal conditions of transport

  — confirming that the radiation levels under normal conditions of transport and hypothetical accident conditions are satisfied (for the hypothetical accident conditions, the package should meet the radiation-level limits without any supplemental shielding)

- The review of operating procedures confirms that the source is securely locked in position before shipment. This review also evaluates procedures to verify by physical means that the source has been removed before shipment of an "empty" package. Because of shielding effectiveness and radiation from uranium shielding itself, verification by radiation measurements alone may not be sufficient. The procedure should be capable of detecting remaining sources if the pigtail is clipped off.

- The review of the acceptance tests and the maintenance program verifies that appropriate fabrication and periodic verification tests are performed to demonstrate effectiveness of the shielding. The review also verifies that appropriate inspections are performed to monitor any wearing of the S-tube.

Several U.S. Nuclear Regulatory Commission (NRC) information notices (INs) (IN-85-07, IN-87-47, IN-88-18, IN-88-33, IN-90-24, IN-90-35, IN-90-82, IN-91-35, IN-92-72, and IN-97-86) provide additional detail on safety issues relevant to the transport of radiography packages.

A.1.6 References

Health Physics Society, "Gamma Radiography—Specifications for the Design, Testing, and Performance Requirements for Industrial Gamma Radiography System Equipment Using Radiation Emitted by a Sealed Radioactive Source," ANSI/HPS N43.9-2015, McLean, VA.

International Atomic Energy Agency, "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition)," Specific Safety Guide No. SSG-26 (STI/PUB/1586), June 2014, Vienna.

National Bureau of Standards, "American National Standard N432; Radiological Safety for the Design and Construction of Apparatus for Gamma Radiography," ANSI N432-1980, Washington, DC, August 15, 1980.

U.S. Nuclear Regulatory Commission, "Contaminated Radiography Source Shipments," Office of Inspection and Enforcement Information Notice 85-07, January 29, 1985.

U.S. Nuclear Regulatory Commission, "Transportation of Radiography Devices," Office of Nuclear Material Safety and Safeguards (NMSS) Information Notice 87-47, October 5, 1987.

U.S. Nuclear Regulatory Commission, "Malfunction of Lockbox on Radiography Device," NMSS Information Notice 88-18, April 25, 1988.

U.S. Nuclear Regulatory Commission, "Recent Problems Involving the Model SPEC 2-T Radiographic Exposure Device," NMSS Information Notice 88-33, May 27, 1988.

U.S. Nuclear Regulatory Commission, "Transportation of Model SPEC 2-T Radiographic Exposure Device," NMSS Information Notice 90-24, April 10, 1990.

U.S. Nuclear Regulatory Commission, "Transportation of Type A Quantities of Non-Fissile Radioactive Materials," NMSS Information Notice 90-35, May 24, 1990.

U.S. Nuclear Regulatory Commission, "Requirements for Use of Nuclear Regulatory Commission- (NRC-) Approved Transport Packages for Shipment of Type A Quantities of Radioactive Material," NMSS Information Notice 90-82, December 31, 1990.

U.S. Nuclear Regulatory Commission, "Labeling Requirements for Transporting Multi-Hazard Radioactive Materials," NMSS Information Notice 91-35, June 7, 1991.

U.S. Nuclear Regulatory Commission, "Employee Training and Shipper Registration Requirements for Transporting Radioactive Materials," NMSS Information Notice 92-72, October 28, 1992.

U.S. Nuclear Regulatory Commission, "Additional Controls for Transport of the Amersham Model No. 660 Series Radiographic Exposure Devices," NMSS Information Notice 97-86, December 12, 1997.

A.2 Type B Waste Packages

A.2.1 Purpose of Package

The purpose of this type of package is to transport a Type B quantity of dewatered or dry, radioactive, irradiated, and contaminated solid materials.

A.2.2 Description of a Typical Package

A typical packaging consists of a steel-encased, lead-shielded cylinder with impact limiters attached at both ends. The packaging may be protected by a thermal shield, consisting of a thin metal shell separated from the lead-filled cylinder by a wire wrap. Closure is provided by a bolted steel lid, which may also include lead shielding. Two concentric O-rings are installed in grooves typically on the underside of the lid. The lid includes a leak-test port between the O-rings and sometimes a vent port. The bottom of the packaging contains a sealed drain port.

A typical packaging may be sized to transport ion-exchange resins, process solids, or irradiated hardware, such as control-rod blades. It is approximately 3.3 m [about 11 feet] in length and 1.3 m [about 4 feet] in diameter (without impact limiters) and can weigh as much as 35 tons (without contents). The packaging generally has two or four trunnions near the top for lifting, and two near the bottom for rotation.

The contents of the package consist of a Type B quantity of dry, radioactive, irradiated, and contaminated solid materials, generally within a secondary container. The maximum content weight may approach 5 tons, including shoring. The radioactive contents typically include waste-containing mixed-fission products and activation products. The fissile material content of these packages is limited to that permitted by the general license provisions in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 71, "Packaging and Transportation of Radioactive Material," for fissile material packages (10 CFR 71.22, "General License: Fissile Material"), or fissile exempt quantities (10 CFR 71.15, "Exemption from Classification as Fissile Material").

A sketch of a typical Type B waste package is presented in Figure A.2-1.

A.2.3 Package Safety

Safety Functions

The principal safety function of the package is to provide gamma shielding and containment.

Safety Features

- The lead shield provides gamma shielding. The neutron source is not typically significant.

- The inner vessel provides containment of the radioactive material. Although secondary containers are often used, they do not provide a containment function.

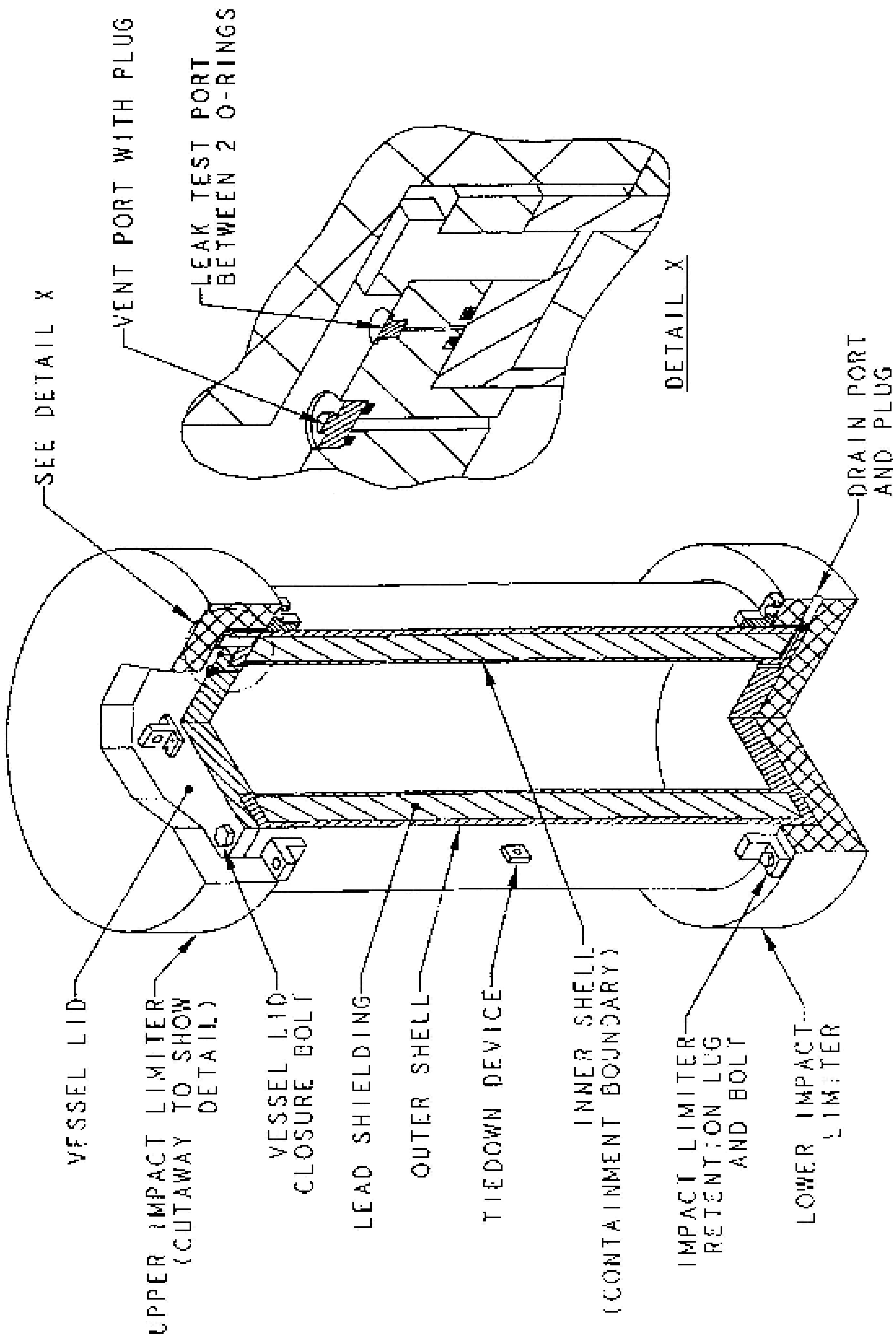

Figure A.2-1 Sketch of a typical Type B waste package

A.2.4 Typical Areas of Review for Package Drawings

- containment vessel body
  - materials of construction
  - dimensions and tolerances of structural shell and shielding material
  - fabrication codes or standards
  - weld specifications, including codes or standards for nondestructive examination
  - thermal shield, if applicable

- containment vessel closures
  - lid materials and their dimensions and tolerances
  - bolt specifications, including number, size, minimum thread engagement, and torque
  - seal material, size, and compression specifications
  - seal groove dimensions
  - vent, drain, and leak-test ports, including closure methods

- impact limiters
  - materials of construction and dimensions
  - foam or wood specifications, including density
  - method of attachment

A.2.5 Typical Areas of Safety Review

- The general information review identifies the allowable contents, including water and other materials that could produce combustible gases.

- The structural and thermal reviews evaluate the performance of the containment system during both normal conditions of transport and hypothetical accident conditions. Primary emphasis is on the structural and thermal effects at the closure regions (lid and ports), including O-rings, plugs, and bolts.

- The structural and thermal reviews also verify the effects of the hypothetical accident conditions tests on the lead shielding and thermal shield (if applicable).

- The thermal review confirms the maximum temperature and pressure in the containment vessel under normal conditions of transport and hypothetical accident conditions.

- The containment review verifies that the package closures (lid, vent port, drain port) meet 10 CFR Part 71 containment criteria using the methods in ANSI N14.5 for both normal conditions of transport and hypothetical accident conditions. A typical maximum allowable leakage rate is approximately 10^{-5} ref cubic centimeters per second. The review also confirms that combustible-gas generation meets the criteria discussed in Chapter 4 of this standard review plan (SRP).

- The shielding review confirms that the package meets the allowable radiation levels during both normal conditions of transport and hypothetical accident conditions. The review should also confirm that the lead shielding does not melt under the hypothetical accident conditions and that any lead slump is appropriately accounted for in the hypothetical accident conditions analysis. Key issues include the following:

- Ensure the application includes an appropriate description of the package contents for defining the radiation source and the source's geometry, including location and distribution, within the package, and self-shielding properties and that the shielding analysis is appropriately bounding for the contents description. Contents specifications may include specific nuclides with maximum activities or maximum specific activities or bounding spectra definitions (i.e., maximum emission or specific emission rates for specific energy ranges) for relevant radiation types the contents emitted.

- Ensure the analysis addresses potential or allowable shifting, settling, or redistribution of radioactive materials or nuclides within the waste contents under normal conditions of transport and hypothetical accident conditions.

- Ensure the analysis is consistent with and bounding for specifications regarding the use of shoring or dunnage with the contents. For cases where shoring is optional, analyses should neglect the shoring, positioning the contents in the package to maximize radiation levels.

- Regulatory Issue Summary 2013-04, "Content Specification and Shielding Evaluations for Type B Transportation Packages," dated April 23, 2013, provides additional useful information regarding content specifications and shielding analyses. Ensure the conditions of the certificate of compliance, including any unique operations descriptions regarding content loading, assure that the shielding analysis will be consistent with or bounding for the allowable contents, including the content configurations.

- Typically, but not always, the criticality review verifies that the package contains no fissile material, an exempt quantity of fissile material, or a fissile material quantity allowed under the general license provisions of 10 CFR Part 71. For packages with fissile content limited to quantities authorized by general license, the review also should confirm that the correct criticality transport index is specified. If the package authorizes fissile material greater than the fissile general license, then a criticality evaluation will be performed.

- The review of operating procedures verifies that the bolts are properly torqued and that all penetrations of the containment vessel are properly leak-tested prior to shipment. The review also addresses procedures that assure the contents are properly dewatered or dry. If not dry, the Containment section of the application should specify the maximum amount of water authorized in the package and evaluate the hydrogen gas generation. The operating procedures for drying should be consistent with the containment evaluation.

- The review of the acceptance tests and the maintenance program confirms that the appropriate leakage tests are performed for fabrication, maintenance, and periodic verification during the service life of the package. The review also ensures that appropriate acceptance testing of the lead shield and thermal performance is described and that the thermal performance of the packaging is maintained during the service life.

Two NRC information notices (IN-96-63 and IN-97-47) provide additional detail on safety issues relevant to the transport of Type B packages.

A.2.6 References

American National Standards Institute, "Radioactive Materials—Leakage Tests on Packages for Shipment," ANSI N14.5-2014, New York.

U.S. Nuclear Regulatory Commission, "Potential Safety Issue Regarding the Shipment of Fissile Material," NMSS Information Notice 96-63, December 5, 1996.

U.S. Nuclear Regulatory Commission, "Inadequate Puncture Tests for Type B Packages Under 10 CFR 71.73(c)(3)," NMSS Information Notice 97-47, June 27, 1997.

U.S. Nuclear Regulatory Commission, "Content Specification and Shielding Evaluations for Type B Transportation Packages," Regulatory Issue Summary 2013-04, April 23, 2013.

A.3 Unirradiated Fuel Packages

A.3.1 Purpose of Package

The purpose of this type of package is to transport commercial unirradiated fuel assemblies and individual fuel rods. These packages are also referred to as "fresh fuel packages."

This appendix addresses only those packages in which the contents are limited to a Type A quantity of fissile material. For entire assemblies, this is typically achieved by restricting the enrichment to less than 20 weight percent. For individual fuel rods, a combination of enrichment and mass limits may be specified. Type AF packages must meet the requirements in 10 CFR 71.43(f).

Transportation packages that contain recycled uranium may be Type B packages; therefore, containment and shielding evaluations may be required. See Chapters 4 and 5 of this SRP, and Section A.10 below for additional guidance.

A.3.2 Description of a Typical Package

A typical packaging consists of a metal outer shell, closed with bolts and a weather-tight gasket. An internal steel strongback, shock-mounted to the outer shell, supports one or two fuel assemblies, which are fixed in position on the strongback by clamps, separator blocks, and end support plates. Depending on the type of fuel, neutron poisons are sometimes used to reduce reactivity. If the package is used to transport individual fuel rods, a separate inner container is often employed.

The contents of the package are unirradiated uranium in fuel assemblies or individual fuel rods. Because the majority of these packages are for commercial reactor fuel, the uranium is typically in the form of Zircaloy-clad uranium dioxide pellets.

Sketches of the typical package described above are presented in Figures A.3-1 and A.3-2.

A.3.3 Alternative Package Design

An alternative design for a fresh fuel package is shown in Figure A.3-3. In this design, the fuel assemblies are fixed in position by two steel channels, mounted by angle irons or a similar bracing structure to a thin-walled inner metal container. This inner container is in turn surrounded by a honeycomb material and enclosed in a wooden outer container. Foam cushioning material is also generally used to cushion the fuel assemblies and may be used between the inner and outer container.

A.3.4 Package Safety

Safety Functions

The principal function of the package is to provide criticality control. The metal outer shell of the packaging retains the assemblies within a fixed geometry relative to other such packages in an array and provides impact and thermal protection. Shielding requirements are not significant because of the low radioactivity of unirradiated fuel.

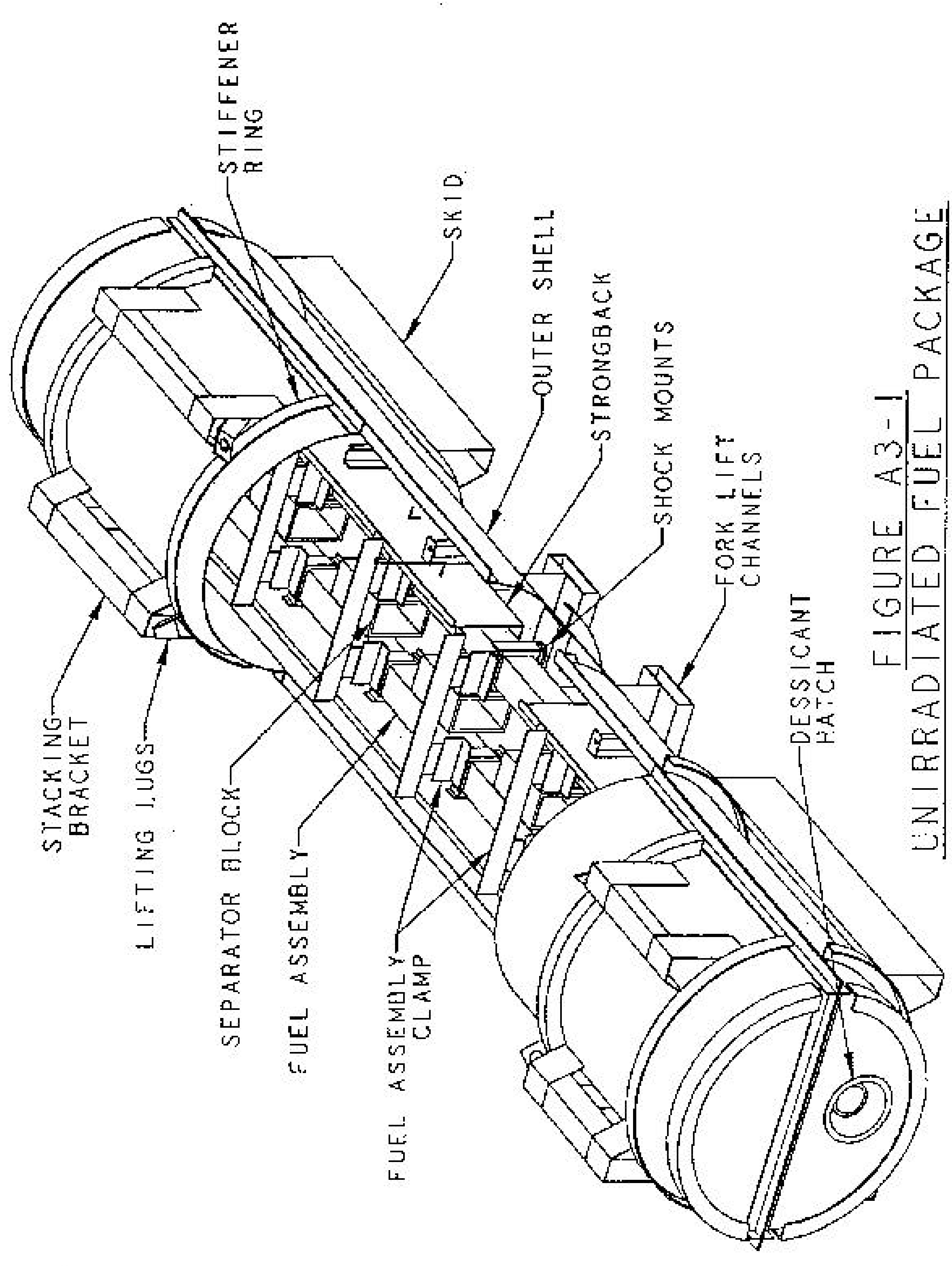

Figure A.3-1 Sketch of a typical unirradiated fuel package

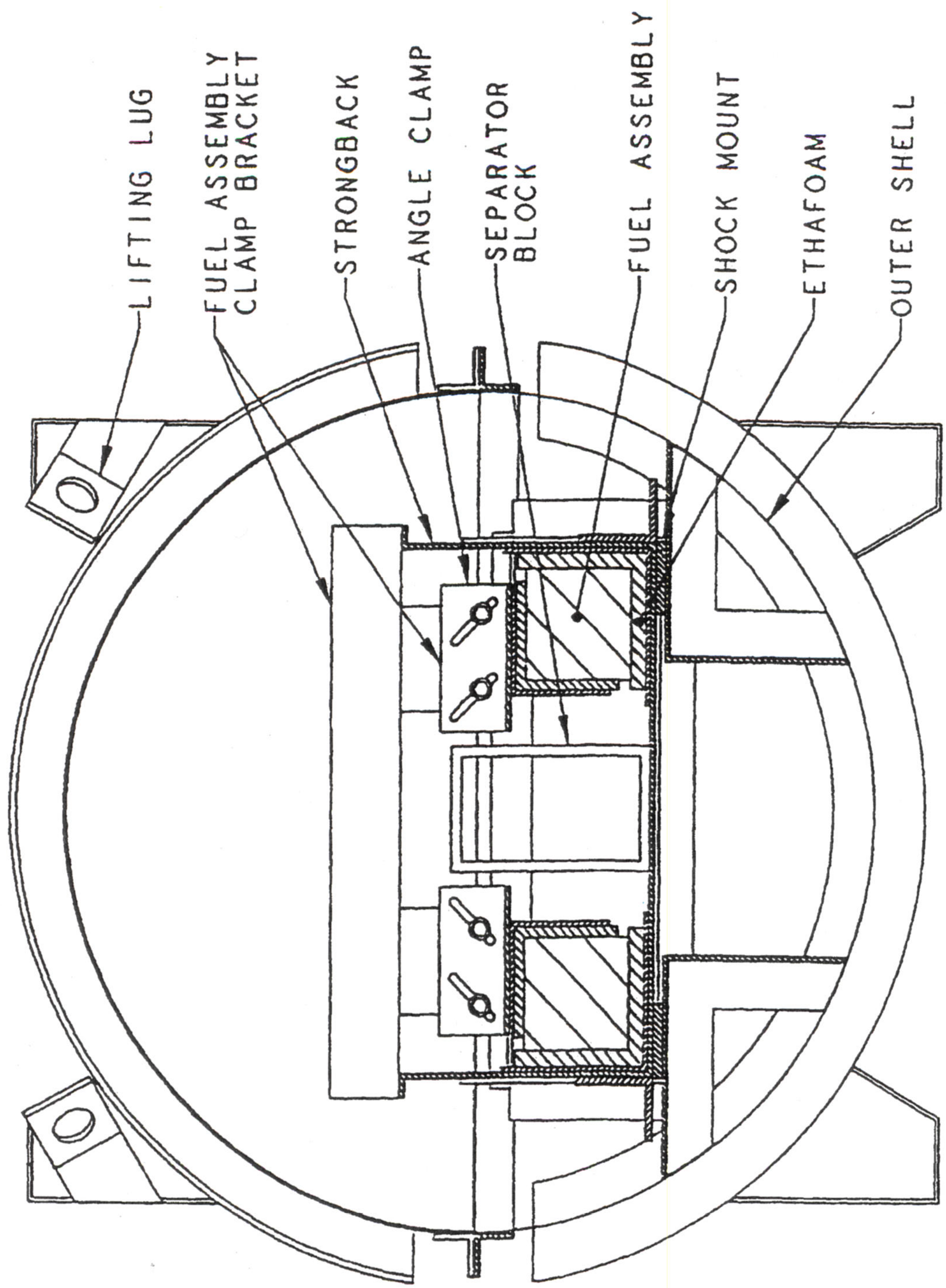

Figure A.3-2 Typical unirradiated fuel package cross section with fuel assemblies

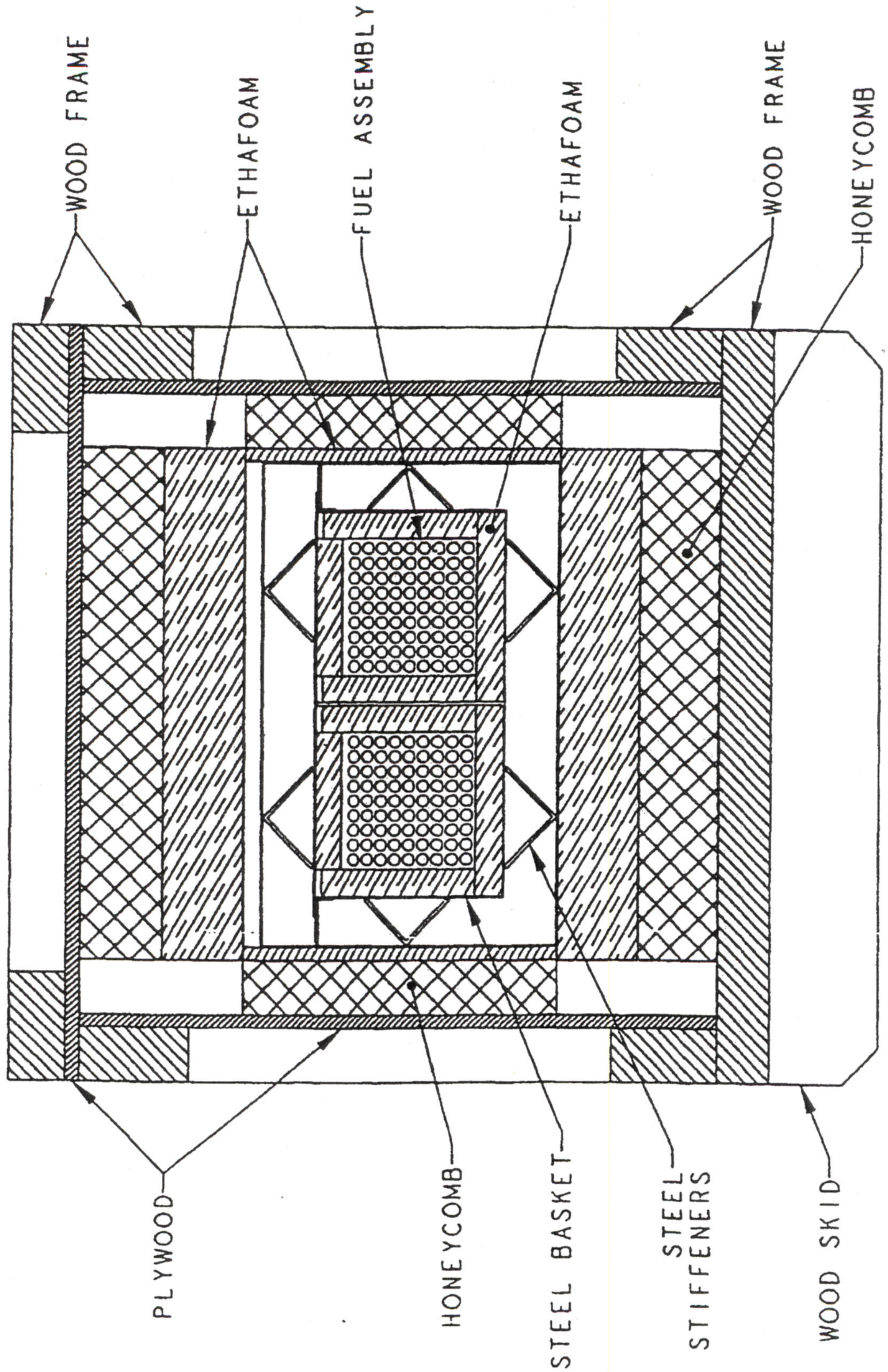

Figure A.3-3 Sketch of an alternative unirradiated fuel package

<u>Safety Features</u>

- A strongback with end support plates, clamps, and separators maintains the fuel assemblies in a fixed position relative to each other and to any neutron poisons.

- The metal outer shell of the packaging retains and protects the fuel assemblies and may provide a minimum spacing between assemblies in an array of packages.

- Neutron poisons, if present, reduce reactivity.

A.3.5 Typical Areas of Review for Package Drawings

- outer shell dimensions

- structural components (e.g., strongback, support plates, fuel clamps, separators) that fix the position of fuel assemblies or relative position between fuel assemblies and poisons

  — dimensions and materials
  — methods of attachment

- neutron poisons

  — dimensions and tolerances
  — minimum poison content
  — location and method of attachment

- moderating materials, including plastics, wood, and foam

  — location
  — material properties

Drawings should include reasonably lenient dimensional tolerances for the packaging components to allow practical fabrication variability. For example, the outer length of the container may vary without affecting the package's performance. Dimensions that are important with respect to criticality safety should be strictly limited. For example, the separation distance provided by certain structural features (e.g., clamps, spacers) may be important for criticality safety, and those features should be identified with close tolerances.

A.3.6 Typical Areas of Safety Review

- The general information review identifies the fuel assembly designs authorized in the package, including the following:

  — number of and arrangement of fuel assemblies

  — number, pitch, dimensions (with tolerances), and position of fuel rods, guide tubes, water rods, and channels

  — material specifications of the cladding, guide tubes, water rods, and channels

  — overall assembly dimensions, including active fuel length

  — authorization or restrictions on missing fuel rods or partial-length rods

- maximum enrichment
- pellet dimensions and tolerances
- minimum cladding thickness
- fuel-clad gap
- type, location, and concentration of burnable poisons
- type, location, and quantity of plastics, such as polyethylene, within or surrounding the fuel assemblies

• The structural review addresses possible damage to the outer shell, strongback, fuel assembly, neutron poisons (if present), clamps, separators, and end support plates to ensure that the fuel assemblies and neutron poisons are maintained in a fixed position relative to each other under hypothetical accident conditions.

• The structural and thermal reviews also confirm the minimum spacing between fuel assemblies in different packages in an array under hypothetical accident conditions. Spacing can be affected by separation of the strongback from its shock mounts, failure of the shock mounts or fuel assembly clamps, and deformation of the outer shell of the package. Damage to the outer shell and charring of any thermal insulating/impact absorbing material (if present) may result in closer spacing than that of normal conditions of transport.

• The thermal review evaluates the effect of the fire on neutron poisons, plastic sheeting, wood, or other temperature-sensitive materials under hypothetical accident conditions.

• The criticality review addresses both normal conditions of transport and hypothetical accident conditions. Key areas for this review include the following:

  - The number of packages in the array and the array configuration (pitch, orientation of packages, etc.): Because of movement of the strongback within the package and the location of poisons, the arrays might not be symmetrical.
  - Degree of moderation: Structural features, as well as packaging material such as plastic sheeting, are evaluated for the possibility of preferential flooding within the package. Plastic sheeting on the fuel assemblies should be open at both ends to preclude preferential flooding. Flooding between the fuel pellets and cladding is also considered. Variations in the allowable amount of lightweight packaging material and plastic shims inserted in the fuel assemblies can also affect criticality under normal conditions of transport.

• The review of operating procedures ensures that instructions are provided so that proper clamps, separators, and poisons are selected for the type of fuel assemblies to be shipped and that these items are properly installed prior to shipment. The procedures should also address any other restrictions (e.g., limits on number of shims and plastic wrappers to limit total polyethylene content) considered in the package evaluation.

- The review of the acceptance tests and the maintenance program verifies that the neutron poisons, if present, are subject to appropriate tests to verify the necessary characteristics, including minimum concentration and uniformity.

A.4 Low-Enriched Uranium Oxide Packages

A.4.1 Purpose of Package

The purpose of this type of package is to transport pellets and powder of low-enriched uranium (LEU) oxide. These packages are also referred to as “low-enriched pellet and powder packages” or “oxide packages.”

This appendix addresses only those packages in which the contents are limited to a Type A quantity of fissile material. This is achieved by limiting either the maximum enrichment or a combination of enrichment and mass.

A.4.2 Description of a Typical Package

A typical packaging consists of an inner steel vessel positioned within an outer steel drum. The outer drum is typically a 30- or 55-gallon drum with a removable head and weather-tight gasket. The head is usually secured by a clamp ring with a closure bolt and a tamperproof seal. Vent holes near the top of the drum, which provide pressure relief under hypothetical accident conditions, are capped or taped during normal conditions of transport to prevent water inleakage.

The inner vessel is typically flanged, with a gasket and a bolted lid. The inner vessel is the containment vessel. It is centered in position inside the outer drum by foam, fiberboard, or similar insulation material. The inner vessel is not a pressure vessel and is not designed to prevent water inleakage under hypothetical accident conditions.

The contents of this package include LEU pellets, powder, and sometimes scrap, which are placed in plastic bags, metal cans, or cardboard boxes prior to loading into the inner container. Pellets are generally arranged on metal trays. Packages may include plates or liners with neutron poisons within the inner vessel. Spacers may be used within the inner vessel to maintain the position of the contents and to displace moderator in the event of water inleakage.

A sketch of a typical package for pellets or powder of LEU oxide is presented in Figure A.4-1.

A.4.3 Package Safety

Safety Functions

The principal function of the package is to provide criticality control. The inner vessel provides containment to satisfy the requirements for Type AF packages. Shielding requirements are not significant because of the low radioactivity of unirradiated uranium oxide. Type AF packages must meet the requirements of 10 CFR 71.43(f).

Safety Features

- The outer metal drum and insulation protect the inner vessel under hypothetical accident conditions and maintain a minimum spacing between the inner containers of different packagings.

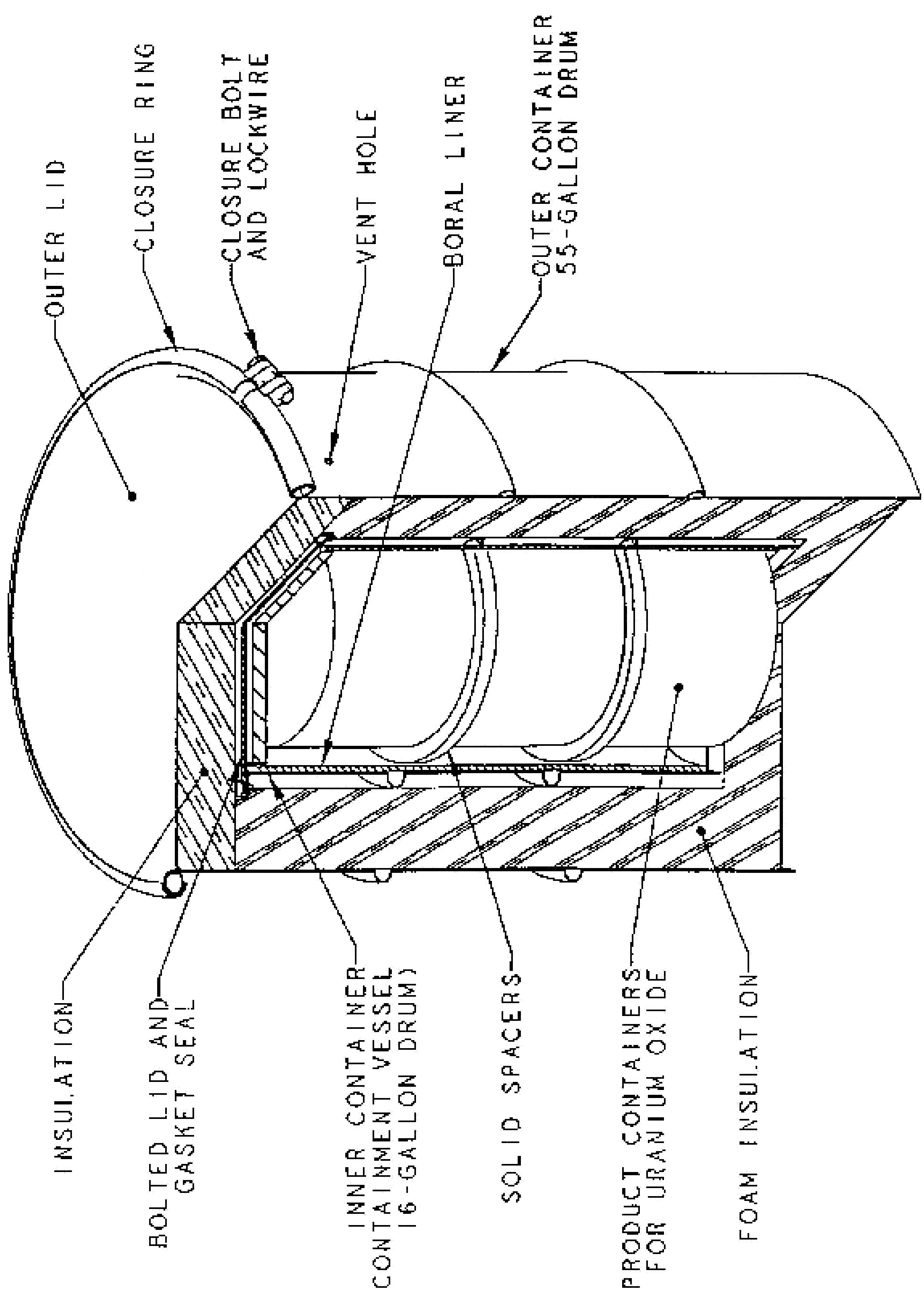

Figure A.4-1 Sketch of a typical package for pellets or powder of LEU oxide

- The inner vessel provides containment and maintains a fixed geometry for criticality control.

- Neutron poisons, if present, reduce reactivity.

A.4.4 Typical Areas of Review for Package Drawings

- inner vessel

  - — materials of construction
  - — dimensions and tolerances, including thickness
  - — product containers
  - — spacers, including materials and dimensions
  - — fabrication codes or standards

- neutron poisons

  - — isotopes and minimum concentration
  - — dimensions and tolerances
  - — location

- insulating material

  - — type
  - — dimensions and tolerances
  - — density

- outer drum

  - — material
  - — closure, including use of heavy-duty clamp ring, bolt torque
  - — dimensions

Drawings should show the outer drum in a general configuration, without precise details. For example, the drawings should show material of construction, which may be “steel” without specification, and relatively lenient tolerances on the drum dimensions. The general configuration of the rolling hoops may be shown, without identifying exact dimensions. Material and thicknesses should be shown for components such as the shell, bottom head, lid, closure ring, and bolt. The gasket, which typically does not serve a containment function, may be shown as an option or with minimum specificity. Dimensions that are important for criticality safety should be appropriately toleranced.

A.4.5 Typical Areas of Safety Review

- The structural review evaluates package integrity under drop, puncture, and thermal tests. This includes verifying that the lid of the outer drum remains in place and that the inner vessel is not damaged. NUREG/CR-6818 discusses potential issues related to steel drum closure lid design.

- The structural and thermal reviews address the minimum spacing between contents of different packages under hypothetical accident conditions. Damage to outer drum and charring of the insulation may result in closer spacing and more reactivity than under normal conditions of transport.

- The thermal review also evaluates the effect of fire on neutron poisons and spacers.

- The criticality review addresses in detail both normal conditions of transport and hypothetical accident conditions. Key areas for this review include the following:

  — The configuration of the contents under normal conditions of transport and hypothetical accident conditions: This includes the number, spacing, size, and condition of pellets, the distribution of powders, and similar effects. Small changes in dimensions of the inner vessel can result in a significant increase in reactivity.

  — Distribution and degree of moderation: In addition to the moisture content of the pellets or powder, structural features, spacers, and packaging material such as plastic bags or cans are evaluated for the possibility of differential flooding within the package. Variations in the allowable amount of lightweight packaging material are also verified. Loading less than the maximum allowed contents can provide additional volume for water inleakage under hypothetical accident conditions; therefore, partial loads are often more reactive than a fully packed inner vessel.

  — The number of packages considered in the array and the array configuration (e.g., pitch and orientation of packages): Depending on the positioning of contents and the location of poisons, the arrays might not be symmetrical.

  — The degree and location of damage (e.g., drying or charring) to the thermal insulation caused by the fire test.

- The review of operating procedures ensures that instructions are provided so that proper neutron poisons or spacers are selected for the type of contents to be shipped and that the package is properly closed.

- The review of the acceptance tests and the maintenance program verifies that the neutron poisons, if present, are subject to appropriate tests to verify their necessary characteristics, including minimum concentration and uniformity.

A.5 Transuranic Waste Packages

A.5.1 Purpose of Package

The purpose of this type of package is to transport a Type B quantity of contact-handled transuranic waste. For remote-handled transuranic waste, the review should consider the guidance provided for spent nuclear fuel content.

A.5.2 Description of a Typical Package

A typical packaging consists of a stainless-steel inner containment vessel housed inside a stainless-steel and polyurethane outer containment assembly.

The outer containment vessel is a right circular cylinder with a flat bottom and domed lid. Its body and dome generally consist of polyurethane foam sandwiched between an inner and outer stainless-steel shell. The dome-shaped lid is secured to the body by a locking ring. An elastomeric O-ring is used as the containment seal; a second O-ring allows the seal to be leak-tested. The assembly typically contains a leak-test port and a vent port. Fork pockets are often located at the base of the assembly for lifting and handling the entire package. Separate lifting devices are used for handling the lid only.

The inner containment vessel is a stainless-steel shell with domed ends. The closure system consists of two O-rings, a leak-test port, and a vent port, similar to the outer containment vessel. Lifting devices on the inner lid can be used for lifting either the lid itself or an empty inner containment vessel.

The contents of the package consist of contact-handled transuranic waste produced primarily from plutonium production operations. The waste may be packaged within secondary containers. The contents may be limited to restrict the generation of hydrogen or other combustible gases.

Several packages may be secured to a special trailer for transport.

A sketch of a typical transuranic waste package is presented in Figure A.5-1.

A.5.3 Package Safety

Safety Functions

The principal safety functions of the package are to provide containment and criticality control.

Safety Features

- While not required by regulation any longer, the inner and outer containment vessels may provide double containment for the plutonium.

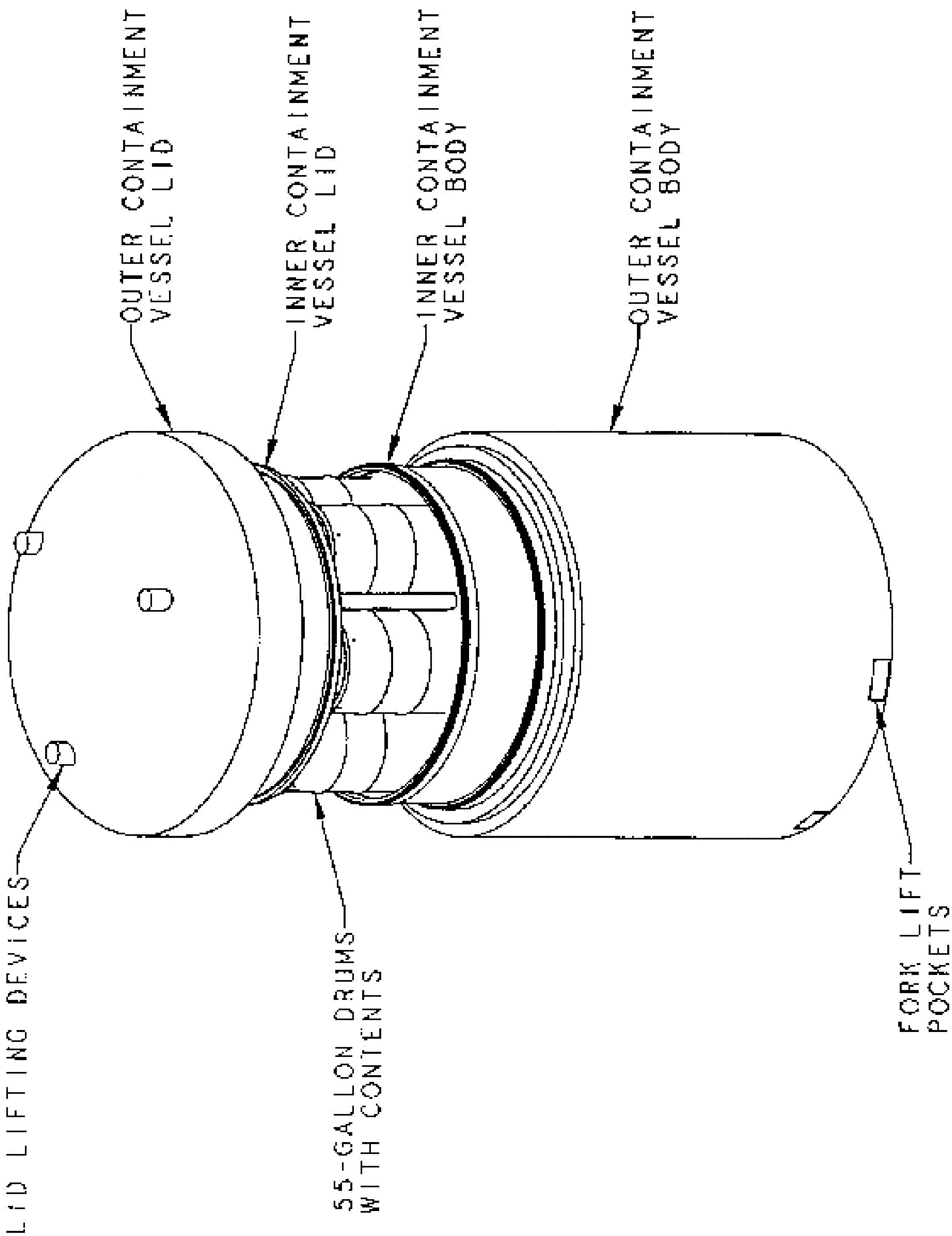

Figure A.5-1 Sketch of a typical transuranic waste package

- The steel package and configuration of the secondary containers provide sufficient attenuation and distance from the waste to satisfy the shielding requirements for normal conditions of transport (exclusive use) and hypothetical accident conditions.

- The limit on the allowed mass of fissile material provides criticality control for a single package. The physical size and separation of contents also ensures subcriticality for arrays.

A.5.4 Typical Areas of Review of Package Drawings

- containment vessels
  - materials of construction
  - dimensions and tolerances
  - fabrication codes or standards
  - weld specifications, including codes or standards for nondestructive examination
  - foam specification and density, as applicable

- containment vessel closures
  - lid materials and their dimensions and tolerances
  - closure device design details, such as bolt specifications and torque
  - seal material, size, and compression specifications
  - seal groove dimensions
  - vent and leak-test ports, including closure methods

A.5.5 Typical Areas of Safety Review

- The structural and thermal reviews evaluate the ability of the containment vessels to perform their intended functions under normal conditions of transport and hypothetical accident conditions. Primary emphasis is on the structural effects near the O-ring regions (including closure devices) and on the thermal performance of the O-rings.

- The thermal and containment reviews verify that the combustible gas concentration in any confined volume will not exceed 5 percent (by volume), or lower if warranted by the combustible gas, during a period of 1 year. Shorter time periods have been approved based on detailed operating procedures to control and track the shipment of packages; this would be documented as a CoC condition. The reviews also should ensure that the containment evaluation specifies that the secondary containers are aspirated (e.g., vacuum dried) prior to shipment.

- The containment review verifies that the 10 CFR Part 71 containment criteria are satisfied for both normal conditions of transport and hypothetical accident conditions. With typical contents, the package should remain leaktight, as defined in ANSI N14.5.

- The shielding review evaluates the ability of the package to satisfy the allowed radiation levels during normal conditions of transport and hypothetical accident conditions.

- The criticality review confirms that a single package and arrays of packages are subcritical during both normal conditions of transport and hypothetical accident conditions.

- The review of operating procedures verifies that if the package is loaded under water, any freestanding water is removed from both containment vessels, and that they are closed and leak-tested prior to shipment. The review also typically ensures that the secondary containers are aspirated prior to shipment.

- Package operations should identify key leakage testing steps, setup configuration, and acceptance criteria. For example, key parameters for a pre-shipment leakage test (e.g., a pressure rise test) may be minimum test duration, maximum pressure drop allowed, and maximum temperature change allowed. These parameters may be justified by calculation of test sensitivity using guidance in ANSI N14.5.

- The review of the acceptance tests and the maintenance program verifies that appropriate fabrication, maintenance, and periodic verification leakage tests are performed.

A.5.6 References

American National Standards Institute, "Radioactive Materials—Leakage Tests on Packages for Shipment," ANSI N14.5-2014, New York.

A.6 <u>Low-Enriched Uranium Hexafluoride Packages</u>

A.6.1 Purpose of Package

The purpose of this type of package is to transport low-enriched solid uranium hexafluoride (UF_6).

A.6.2 Description of a Typical Package

A typical packaging consists of an inner steel cylinder that acts as a containment vessel, and an outer protective overpack. Unenriched UF_6 may be transported in bare cylinders, without the protective overpack, as authorized in U.S. Department of Transportation (DOT) regulations. Protective overpacks are typically required only for the transport of enriched (fissile) UF_6. ANSI N14.1, "Nuclear Materials—Uranium Hexafluoride—Packagings for Transport," specifies the design and fabrication of the UF_6 cylinder. ANSI N14.1 and USEC-651, "The UF_6 Manual: Good Handling Practices for Uranium Hexafluoride," contain information regarding overpacks. In 49 CFR 173.420(a)(2)(i), the DOT requires that the packagings must be "designed, fabricated, inspected, tested and marked in accordance with—(i) American National Standard N14.1 in effect at the time the packaging was manufactured."

The inner cylinder is carbon steel, with rounded ends and a protective skirt. On one end of the cylinder is a valve for filling and emptying the cylinder; on the other end is a removable plug. The most commonly used commercial cylinders are approximately 0.76 m [30 inches (in.)] in diameter, 2.1 m (81 in.) in length, with a capacity of about 2,300 kilograms (2.5 tons) of UF_6. The design and authorized contents are defined in ANSI N14.1.

The protective overpack is generally a double-shell, stainless-steel cylinder with cushioning pads on the inner cavity. An energy-absorbing, insulating foam fills the space between the inner and outer shell. The overpack can be separated into two halves to enable easy access to the inner cylinder. Overpacks for the 30-in. cylinders mentioned above are approximately 0.016 m (4 in.) thick.

For the 30-in. cylinder, the UF_6 enrichment should not exceed 5 percent. The cylinder is filled with liquid UF_6. Because of volume reduction during cooling and solidification of the UF_6, the final internal pressure is less than 1 atmosphere in the cylinder.

A sketch of a typical UF_6 package (cylinder and overpack) is presented in Figure A.6-1.

A.6.3 Package Safety

Safety Functions

The primary function of the package is to provide containment and moderation control for criticality purposes. Moderation control is required for all commercially used cylinders for fissile UF_6 and must be maintained under normal conditions of transport and hypothetical accident conditions. To assure subcriticality by moderation control, the mass of the contents must be at least 99.5 percent UF_6.

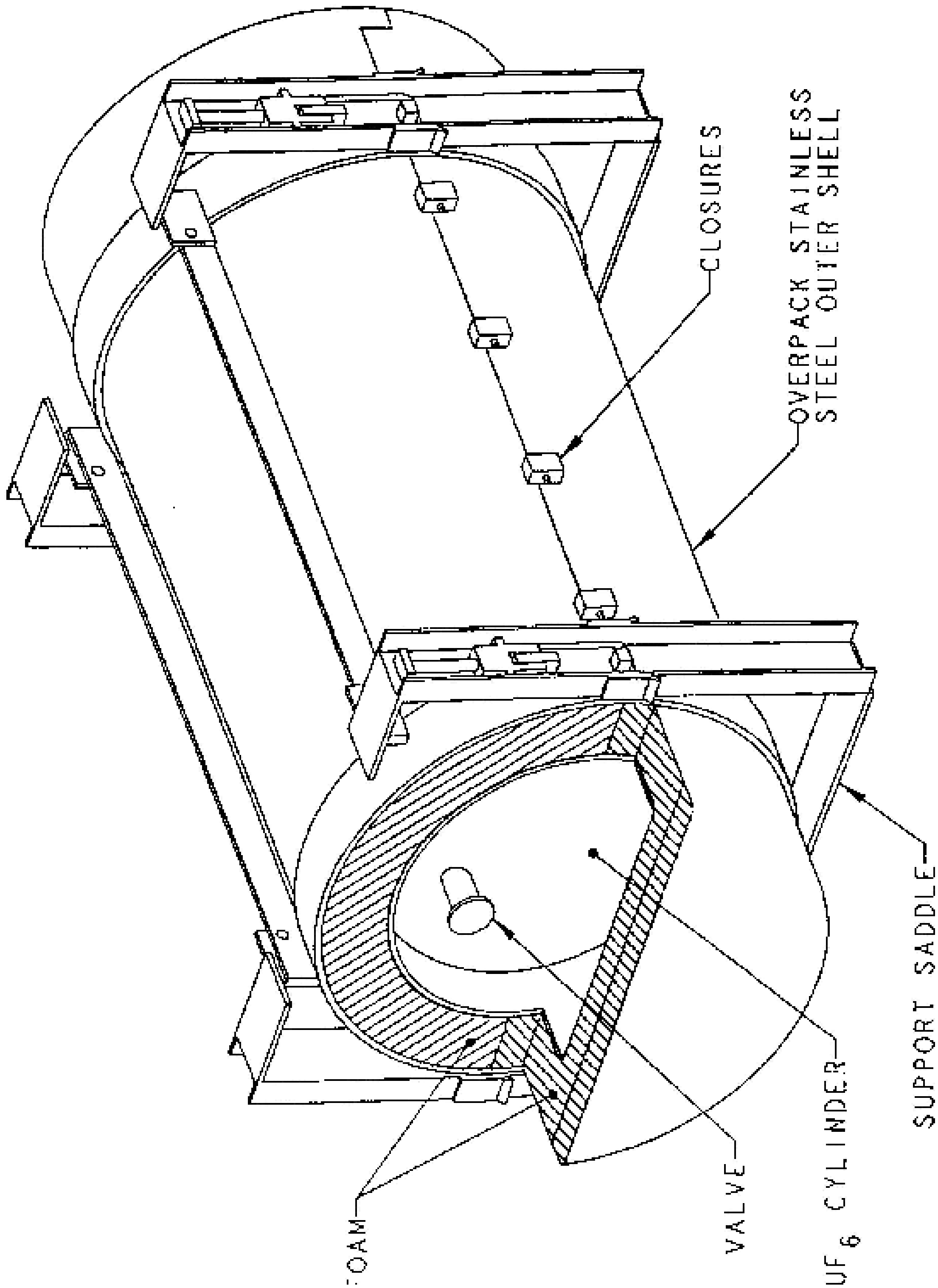

Figure A.6-1 Sketch of a typical UF_6 package (cylinder and overpack)

The cylinder is defined as the containment boundary for the UF_6. Unirradiated uranium enriched to less than 5 percent is a Type A quantity. Recycled uranium can be a Type B quantity due the presence of uranium-232, uranium-234, uranium-236, and various radioactive impurities.

Shielding requirements are generally not significant because of the low radioactivity and self-shielding of UF_6. If the contents are recycled uranium, the shielding evaluation should show that the package will meet the dose rate limits in 10 CFR 71.47, "External Radiation Standards for All Packages," and 10 CFR 71.51, "Additional Requirements for Type B Packages," during normal conditions of transport and hypothetical accident conditions, respectively. Compliance with regulatory limits for radiation levels is verified prior to shipment.

The overpack provides thermal protection to prevent overheating of the UF_6, which can cause hydraulic failure of the cylinder. The overpack also provides impact protection for the cylinder and the valve.

Safety Features

- The steel cylinder precludes inleakage of water and provides containment under normal conditions of transport and hypothetical accident conditions.

- The cylinder skirt provides some protection to the valve during handling operations, normal conditions of transport, and hypothetical accident conditions.

- The overpack provides structural and thermal protection for the cylinder and its valve under hypothetical accident conditions.

A.6.4 Typical Areas of Review for Package (Overpack) Drawings

- overpack shell
    - materials of construction
    - dimensions and tolerances
    - vents for pressure relief of foam combustion products

- foam specifications
    - type
    - density
    - compressive strength
    - fire retardant characteristics
    - limit on free chlorides

- closure devices
    - torque
    - valve protection device

A.6.5 Typical Areas of Safety Review

- The structural review concentrates on the ability of the overpack to protect the valve under hypothetical accident conditions. Note that 10 CFR 71.55(g) specifically addresses moderator exclusion [i.e., exception from the requirements in 10 CFR 71.55(b)] in UF_6 packages, in part, in terms of the post-hypothetical accident conditions configuration of the valve body and other components of the packaging.

- The structural and thermal reviews address the ability of the overpack to provide protection to the cylinder itself under hypothetical accident conditions. Because of the heat capacity of the UF_6 and the high pressure that can result due to a phase change at high temperatures, a partially filled cylinder may be more susceptible to hydraulic failure than a full cylinder.

- The containment review verifies that the cylinder meets the containment criteria in ANSI N14.5 for Type B packages.

- The criticality review confirms that there is no water inleakage under normal conditions of transport and hypothetical accident conditions. For UF_6 packages that meet the requirements in 10 CFR 71.55(g), the minimum criticality safety index (CSI) is 5.0 based on design and regulatory practice to date. For other UF_6 packages, the minimum CSI will be determined on a case-by-case basis.

- The review of operating procedures ensures that the valve is properly closed and leak-tested, as appropriate, and that the valve protection device, if applicable, is installed. This review also confirms that the radiation levels are verified to meet the regulatory limits prior to transport.

- The review of the acceptance tests and the maintenance program evaluates the inspection procedures for the overpack, including the physical condition of the inner and outer shells, corrosion, performance of the foam while the overpack is in service, and wear of cushioning pads between the cylinder and overpack. The review also verifies that the cylinder is tested and maintained in accordance with the requirements in 49 CFR 173.420, "Uranium Hexafluoride (Fissile, Fissile Excepted and Nonfissile)," and ANSI N14.1. For foam-filled overpacks, the acceptance tests for the foam should include reasonable ranges for material density, compressive strength, thermal conductivity, etc. Structural analyses may be used to justify the ranges. Reference to American Society for Testing and Materials International standards should be reviewed to ensure that the standard does not overly restrict the testing of foam characteristics.

Several NRC information notices (IN-92-58, IN-97-24, IN-97-20, and IN-16-06) and Bulletin 94-02 provide additional detail on safety issues relevant to the transport of uranium hexafluoride packages.

A.6.6 References

American National Standards Institute, "Radioactive Materials–Leakage Tests on Packages for Shipment," ANSI N14.5-2014, New York.

Institute for Nuclear Materials Management, "Nuclear Materials—Uranium Hexafluoride—Packagings for Transport," ANSI N14.1-2012, New York.

U.S. Enrichment Corporation, "The UF_6 Manual: Good Handling Practices for Uranium Hexafluoride," USEC-651, Revision 10, 2017.

U.S. Nuclear Regulatory Commission, “Corrosion Problems in Certain Stainless Steel Packagings Used to Transport Uranium Hexafluoride,” NRC Bulletin 94-02, November 14, 1994.

U.S. Nuclear Regulatory Commission, “Uranium Hexafluoride Cylinders—Deviations in Coupling Welds,” NMSS Information Notice 92-58, August 12, 1992.

U.S. Nuclear Regulatory Commission, “Identification of Certain Uranium Hexafluoride Cylinders that Do Not Comply with ANSI N14.1 Fabrication Standards,” NMSS Information Notice 97-20, April 17, 1997.

U.S. Nuclear Regulatory Commission, “Failure of Packing Nuts on One-Inch Uranium Hexafluoride Cylinder Valves,” NMSS Information Notice 97-24, May 8, 1997.

U.S. Nuclear Regulatory Commission, “Uranium Hexafluoride Cylinders with Potentially Defective 1-Inch Valves,” NMSS Information Notice 16-06, May 12, 2016.

A.7 High-Enriched Uranium or Plutonium Packages

A.7.1 Purpose of Package

The purpose of this type of package is to transport Type B quantities of high-enriched uranium or plutonium (other than by air).

A.7.2 Description of a Typical Package

A typical packaging consists of a containment vessel and an outer container. Note that some older packages for transport of plutonium may have two containment boundaries. This is because prior to the NRC’s 2004 rule change, plutonium quantities in excess of 20 Ci required double containment.

The outer container is a steel drum with a removable head and weather-tight gasket. The head is usually secured by a clamp ring with a tamperproof seal. Vent holes near the top of the drum, which provide pressure relief under hypothetical accident conditions, are capped or taped during normal conditions of transport to prevent water inleakage.

The inner containment vessel is a steel container, typically a stainless-steel cylinder, with a maximum outer diameter of 0.127 m (5 in.), closed by a welded bottom cap and a welded top flange with a bolted lid. The lid, which is sealed by two O-rings, contains a leak-test port and sometimes a separate fill port for leak testing. Unless double containment is provided, this containment vessel is centered in position inside the outer container by fiberboard (or similar material) insulating material. If the package contains a second containment vessel, then the inner (primary) containment vessel is positioned inside a secondary containment vessel.

The contents are uranium or plutonium, typically in metal, oxide, or nitrate form. The uranium or plutonium is generally placed in plastic bags or metal cans prior to loading into the containment vessel. Spacers are often used to maintain the position of the contents. While uranium may be in liquid form (if so, verify there is sufficient ullage or other specified provision for expansion of the liquid), shipments of plutonium in excess of 20 Ci must be shipped as a solid.

A sketch of a typical package for high-enriched uranium is presented in Figure A.7-1. A package for plutonium would be similar, except that a second containment system may be present.

A.7.3 Package Safety

Safety Functions

The principal functions of the package are to provide containment and criticality control.

Package design features that accomplish the containment and criticality functions generally also provide adequate shielding to satisfy the requirements for nonexclusive-use shipment. Additional shielding may be required if significant quantities of certain isotopes [e.g., plutonium-238 or americium-241 (from the decay of plutonium-241)] are present.

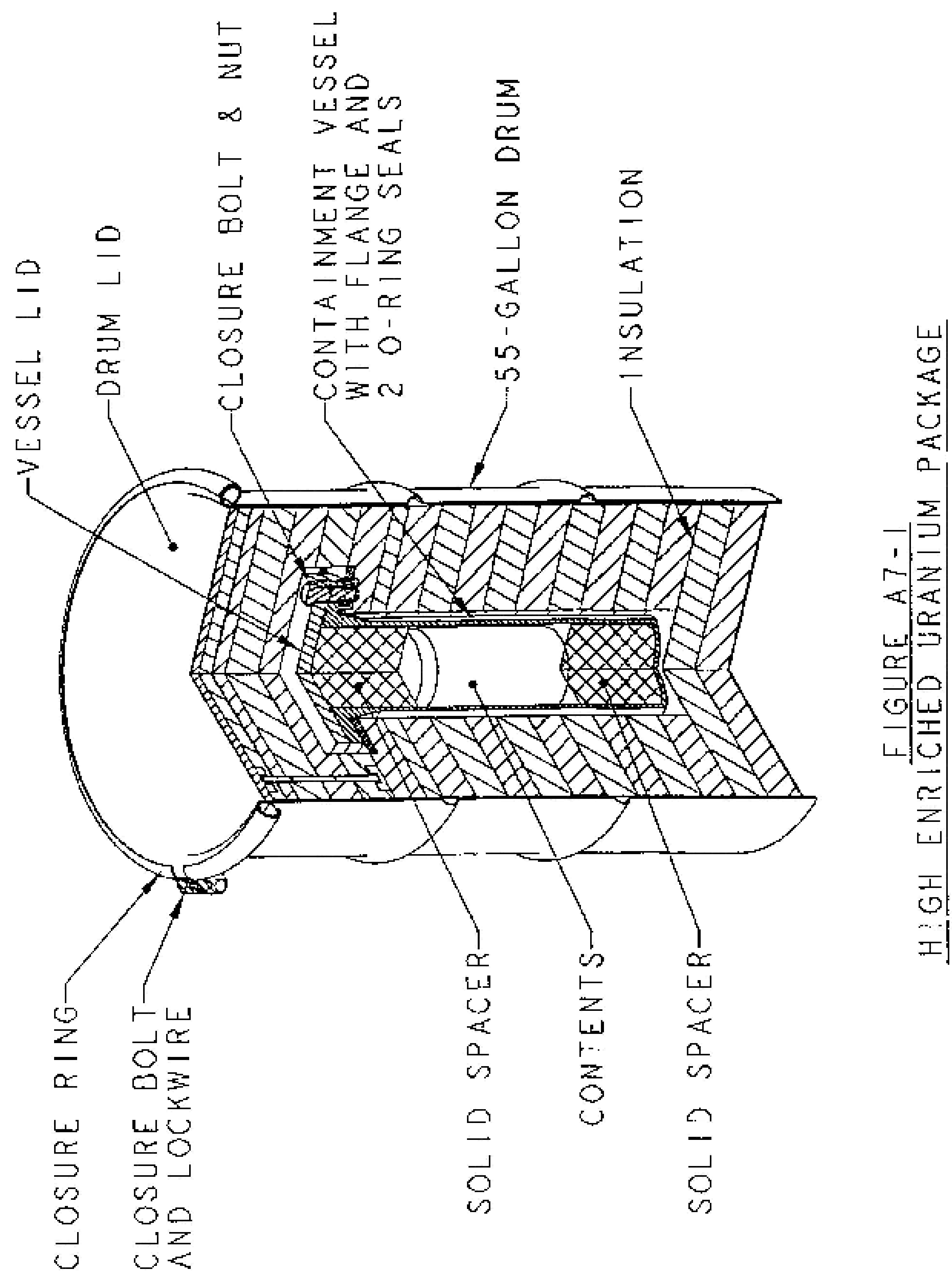

Figure A.7-1 Sketch of a typical package for high-enriched uranium

Safety Features

- The steel drum and insulating material protect the containment vessel and contents under hypothetical accident conditions and maintain a minimum spacing between packagings for criticality control.

- The steel inner vessel provides containment of the radioactive material. An additional containment vessel may provide containment for plutonium.

- The diameter and volume of the inner containment vessel, together with limits on the fissile mass of the contents, ensure that a single package is subcritical.

- The containment vessel, insulating material, and steel drum maintain a minimum distance from the contents to the package surface and provide some attenuation to satisfy the shielding requirements.

A.7.4 Typical Areas of Review for Package Drawings

- containment vessel body

  — materials of construction
  — dimensions and tolerances, including maximum cavity dimensions
  — fabrication codes or standards
  — weld specifications, including codes or standards for nondestructive examination

- containment vessel closures

  — lid materials, dimensions, and tolerances
  — bolt specifications, including number, size, and torque
  — seal material, size, and compression specifications
  — seal groove dimensions
  — leak-test ports

- spacers to position or displace fissile material

  — material of construction
  — dimensions and tolerances
  — locations

- insulating material

  — type
  — dimensions and tolerances
  — density

- outer drum

  — material
  — closure, including use of heavy-duty clamp ring, bolt torque
  — dimensions
  — applicable codes or standards

A.7.5 Typical Areas of Safety Review

- The structural review confirms that packaging integrity is maintained under the drop, crush, and puncture tests. The review also verifies that the drum lid remains securely in place. NUREG/CR-6818 discusses potential issues related to steel drum closure lid design.

- The structural and thermal reviews evaluate the performance of the containment system under both normal conditions of transport and hypothetical accident conditions. Primary emphasis is on the structural integrity of the inner vessel and its closure, and on the thermal performance of the O-rings.

- The structural and thermal reviews address the condition of the package and the minimum spacing between different packages under hypothetical accident conditions. Damage to the outer drum and charring of the insulating material may result in closer spacing than that of normal conditions of transport.

- The thermal and containment reviews verify that the combustible gas concentration in any confined volume will not exceed 5 percent (by volume), or lower if warranted by the combustible gas, during a period of 1 year. Shorter time periods have been approved based on detailed operating procedures to control and track the shipment of packages; this would be documented as a CoC condition.

- The criticality review addresses in detail both normal conditions of transport and hypothetical accident conditions. Key parameters for this review include the number of packages in the arrays, array configuration (pitch, orientation of packages, etc.), positioning of the containment vessels within the drum, moderation due to inleakage of water, the condition and quantity of spacing material, and interspersed moderation between packages.

- The contents specification may include multiple loadings, each of which is separately evaluated for criticality safety. Such multiple loadings may include ranges of fissile material enrichment, ranges of hydrogen atoms per atom of fissile material (H/X), and minimum CSI. The applicant may construct the multiple loadings, including ranges that satisfy criticality safety requirements, so as to allow maximum flexibility for operations.

- The review of operating procedures confirms that the containment vessels have been properly closed and bolts torqued, and that an appropriate pre-shipment leak test is performed.

- The review of the acceptance tests and the maintenance program verifies that appropriate fabrication, maintenance, and periodic verification leakage tests are performed.

A.8 <u>Type B Special Form Packages</u>

A.8.1 Purpose of Package

The purpose of this type of package is to transport a Type B quantity of radioactive material in special form.

A.8.2 Description of a Typical Package

A typical packaging consists of a package body with a lid, base, and protective jacket.

The package body is a lead-filled cylinder with a stainless-steel inner and outer shell. A drain tube penetrates the cavity and is sealed with a plug, which is covered by the protective jacket during transport. A lead-filled (or other high-density shielding material), stainless-steel lid is bolted to the tapered top of the main body and sealed with a weather-tight gasket. Both the body and the lid generally have lifting devices that are covered during shipment by the protective jacket (overpack).

The base is a square steel skid that bolts to the protective jacket. The skid consists of energy-absorbing steel angles (stiffeners). Several I-beams are welded to the base to enable handling by a forklift.

The protective jacket is a double-walled steel cylinder with an open bottom and a protruding box section positioned diametrically across the top and vertically down the sides. The jacket may contain thermal insulation. A steel flange bolts to the base, and the main body of the packaging is centered within the jacket by steel tubes welded to the jacket inner wall. Steel lifting loops are typically welded to the top corners, and tie-down devices are welded to the sides.

The contents of the package typically consist of byproduct material in special form. A sketch of a typical Type B special form package is presented in Figure A.8-1.

A.8.3 Package Safety

Safety Functions

The principal safety function of the package is to provide radiation shielding. Containment is provided primarily by the special form source itself. The packaging must maintain the sources in the fully shielded configuration under normal conditions of transport and hypothetical accident conditions.

Safety Features

- The lead shield or other high-density shielding material (e.g., depleted uranium) provides shielding for gamma radiation.

- The protective jacket provides structural and thermal protection to the main body, which contains the special form radioactive material.

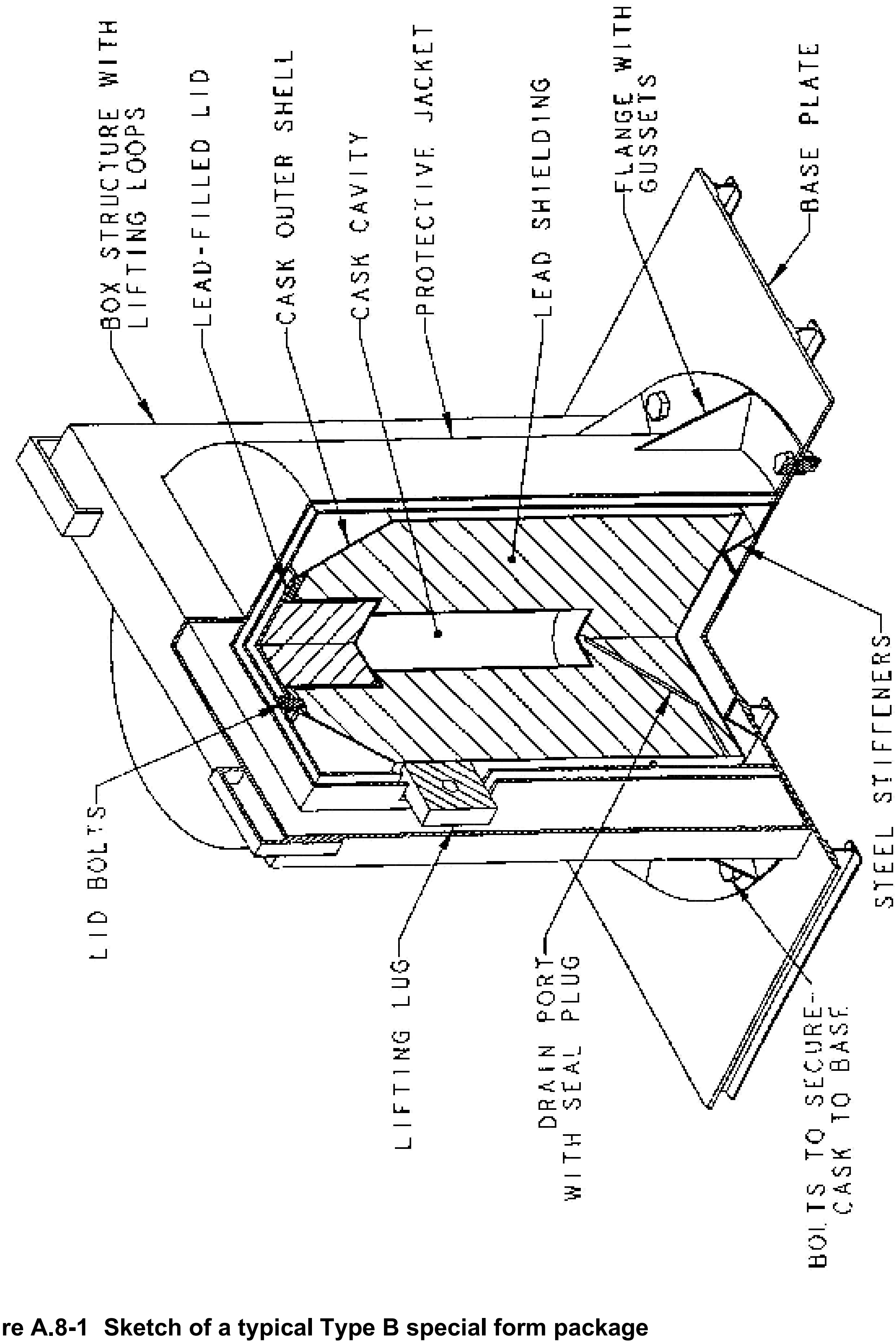

Figure A.8-1 Sketch of a typical Type B special form package

A.8.4 Typical Areas of Review for Package Drawings

- package body

    - materials of construction
    - dimensions and tolerances of steel shells and gamma shield
    - fabrication codes or standards, including any special processes for lead pour
    - weld specifications, including codes or standards for nondestructive examination

- closures

    - lid materials and their dimensions and tolerances
    - bolt specifications, including number, size, minimum thread engagement, and torque
    - seal material, size, and compression specifications
    - seal groove dimensions
    - vent and leak-test ports, including closure methods

- protective jacket

    - method of attachment
    - bolt specifications, including number, size, minimum thread engagement, and torque
    - insulating material

A.8.5 Typical Areas of Safety Review

- The review of the general information verifies that the contents are special form. Note that the certificate of compliance will be conditioned to require the contents to be in special form.

- The structural and thermal reviews evaluate the ability of the shield to perform its intended function under normal conditions of transport and hypothetical accident conditions. Lead slumping should be inconsequential, and the lead should not melt. For packages with depleted uranium shields, the package design should ensure that the damage from the drop and puncture tests does not allow the depleted uranium to be exposed to air during the thermal test, to prevent oxidation of the depleted uranium. These reviews ensure that the package has been tested under the most damaging conditions (e.g., impact orientation). The integrity of the package closure and bolts is also reviewed.

- The thermal review should verify that no credit has been taken for the presence of helium in gaps between packaging components. The review should verify that the heat transfer medium is air, and that the effects of air on the contents and packaging components have been addressed.

- The shielding review evaluates the ability of the package to satisfy the allowed radiation levels during both normal conditions of transport and hypothetical accident conditions.

- The review of operating procedures verifies that the package has been appropriately drained and that the bolts are properly torqued.

- The review of the acceptance tests and the maintenance program ensures that appropriate tests are specified for shielding and thermal performance.

- O-ring seals for packages containing special form sources may have limited safety significance (e.g., weather shield), because most of the radioactivity is within the special form source. O-rings would retain any contamination that might be within the package and introduced during source loading, etc. O-ring seals may be shown in a general configuration, and optional materials may be shown. O-ring replacement schedules may be omitted, provided that the O-ring is inspected and replaced when damaged.

A.9 Mixed Oxide Powder and Pellet Packages

A.9.1 Purpose of Package

The purpose of this type of package is to transport Type B quantities of mixed-oxide (MOX) material (other than by air).

A.9.2 Description of a Typical Package

A typical packaging consists of an inner containment vessel or vessels and an outer container that serves to confine the package's internals. The outer container is a steel drum with a removable head and weather-tight gasket. The head usually is a bolted or clamped lid with a tamperproof seal. Vent holes near the top of the drum, which provide pressure relief from combustion gases or off-gassing from insulating materials under hypothetical accident conditions, are capped or taped during transport to prevent water inleakage.

The inner containment vessel is a steel container, typically a stainless-steel cylinder, with a maximum inner diameter of 0.127 m (5 in.), closed by a welded bottom cap and a welded top flange with a bolted lid. The lid, which is generally sealed by two O-rings, contains a leak-test port and sometimes a separate fill port for leak testing.

A product container may be used and may be designed similar to the primary containment vessel. It can include welded and bolted bottom cap and top flange, respectively; dual O-ring seals; a leak test port; and sometimes a separate fill port for leakage testing. (See, for example, Figure A.9-1.)

The contents are MOX powder or pellets. The MOX powder or pellets are generally placed in metal cans prior to loading into the containment vessel. Solid spacers are often used to maintain the position of the contents.

Note that essentially all packages shipping bulk unirradiated MOX powder and pellets will be designated as Category I packages per Regulatory Guide 7.11, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)." Also, because of the greater radiological hazard of MOX (vs. LEU), MOX requires shipment in a Type B package.

A sketch of a typical package with an optional inner containment vessel is shown in Figure A.9-1.

A.9.3 Package Safety

Safety Functions

The principal functions of the package are to provide containment, shielding, and criticality control. Package design features that accomplish the containment and criticality functions might also provide adequate shielding to satisfy the requirements for nonexclusive-use shipment. Additional shielding may be required if significant quantities of certain isotopes [e.g., plutonium-236, plutonium-238, plutonium-241, or americium-241 (from the decay of plutonium-241)] are present in the MOX material.

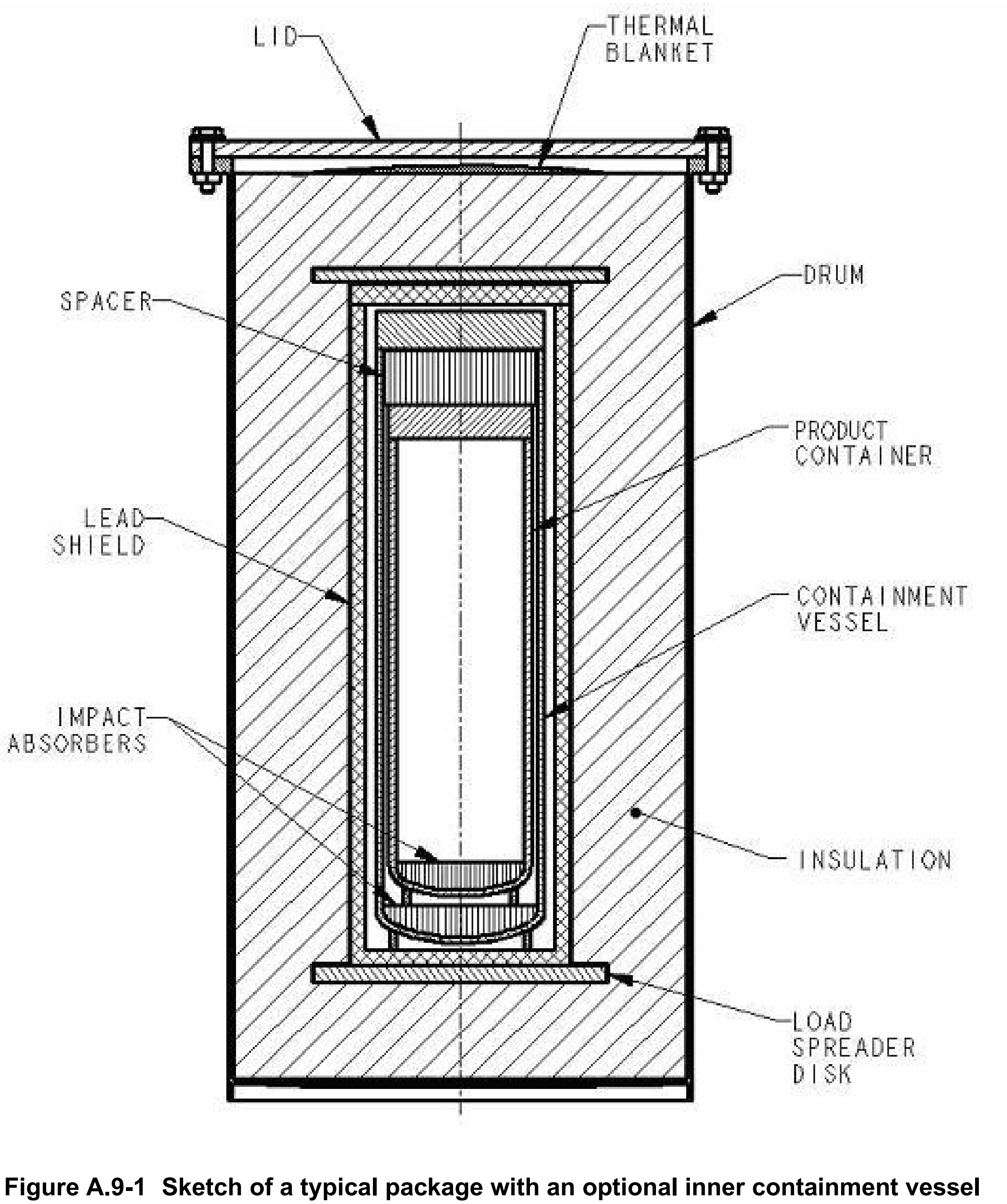

Figure A.9-1 Sketch of a typical package with an optional inner containment vessel

Safety Features

- The steel drum and thermal insulating/impact absorbing material protect the containment vessel(s) and contents and maintain a minimum spacing between packages for criticality control.

- Typically, the inner vessel(s) provides containment of the radioactive material.

- The diameter and volume of the inner containment vessel(s), together with limits on the fissile mass of the contents, ensure that a single package is subcritical, even with water inleakage.

- The containment vessel(s), thermal insulating/impact absorbing material, and steel drum maintain a minimum distance from the contents to the package surface and provide some attenuation to satisfy the shielding requirements.

A.9.4 Typical Areas of Review for Package Drawings

- containment vessel body

  — materials specifications
  — dimensions and tolerances, including maximum cavity dimensions
  — fabrication codes or standards
  — weld specifications, including codes or standards for nondestructive examination

- containment vessel closures

  — lid material specifications, dimensions, and tolerances
  — bolt specifications, including number, size, material, and torque
  — seal material specifications and size
  — seal groove dimensions
  — leak-test ports
  — applicable codes and standards

- spacers to position or displace fissile material

  — material of construction
  — dimensions and tolerances
  — locations

- thermal insulating/impact absorbing material

  — type and specifications
  — dimensions and tolerances
  — density

- outer drum

  — material specifications, including lid and closure device
  — closure bolt specifications, including number, size, material, and torque
  — dimensions and tolerances

- applicable codes or standards

- neutron poisons

  - dimensions and tolerances
  - minimum poison content
  - location and method of attachment
  - material specifications
  - applicable codes and standards

- gamma- and neutron-shielding materials

  - material specifications
  - dimensions and tolerances

A.9.5 Typical Areas of Safety Review

- The review considers the characteristics of MOX materials described in Appendix B to this SRP for shielding and thermal reviews. This includes the higher specific content decay heat rate (vs. LEU material) for the thermal review and the need to evaluate the radiation source term as for other Type B packages (e.g., spent nuclear fuel, others) for the shielding review.

- The structural review confirms that packaging integrity is maintained under both normal conditions of transport and hypothetical accident conditions, particularly the drop, crush, and puncture tests. The review also verifies that the drum lid remains securely in place and the drum body and closure have no unacceptable openings that would cause the safety performance of the package to not meet regulatory standards, especially during the fire test.

- The structural and thermal reviews evaluate the performance of the containment system under both normal conditions of transport and hypothetical accident conditions. Primary emphasis is on the structural integrity of the containment vessel and its closure, and on the thermal performance of the O-rings. Failure of the lift and tie-down devices should not impair the containment system's ability to perform its functions.

- The structural and thermal reviews address the condition of the package and the minimum spacing between different packages under hypothetical accident conditions. Damage to the outer drum and charring of the thermal insulating/impact-absorbing material may result in closer spacing than that of normal conditions of transport.

- The thermal and containment reviews verify that the combustible gas concentration in any confined volume will not exceed 5 percent (by volume), or lower if warranted by the combustible gas, during a period of 1 year. Shorter time periods have been approved based on detailed operating procedures to control and track the shipment of packages; this would be documented as a CoC condition.

- The thermal review evaluates the maximum normal operating pressure of the package similar to what is done for plutonium oxide powder and pellet packages, accounting for the possibility of gases (hydrogen, others) generated by thermal or radiation decomposition of moisture in impure plutonium-containing oxide powders (contribution is expected to be small).

- The thermal review, for hypothetical accident conditions, (1) evaluates the package at the maximum heat load of the contents unless a lower value is more unfavorable and (2) considers any increase in pressure from helium released from the contents with increasing temperatures (this pressure contribution is expected to be small because the temperature increase is small versus processing temperatures).

- The containment review evaluates the containment design criteria to ensure they are appropriately and correctly applied to the containment system and the criteria are supported by calculations that demonstrate the package meets the regulatory limits for releases.

- The shielding review evaluates the ability of the package to satisfy the allowed radiation levels during both normal conditions of transport and hypothetical accident conditions.

- The shielding review evaluates the radiation source terms for appropriate consideration of contributing aspects of the contents. This includes accounting for plutonium-236, plutonium-238, plutonium-239, plutonium-240, plutonium-241, plutonium-242, and americium-241 (from plutonium-241 decay) when these nuclides are present in the contents for their contributions to the gamma- and neutron-source terms. This also includes ensuring consideration of (α, n) reactions, spontaneous fission and neutron multiplication contributions to the neutron source, and definition of an appropriate energy structure of the neutron source. Appendix B to this SRP describes different gamma and neutron emission rates for various transuranic elements and MOX with different grades of plutonium.

- The criticality review addresses, in detail, both normal conditions of transport and hypothetical accident conditions. Key parameters for this review include the number of packages in the arrays, array configuration (e.g., pitch, orientation of packages), the physical condition and properties of packaging components, positioning of the containment vessel within the drum, moderation due to inleakage of water, the condition and quantity of spacing material, interspersed moderation between packages, preferential flooding of different regions within the package, packaging materials that provide moderation (e.g., plastics), and neutron poisons.

- For the criticality review, the differences between the package and benchmark experiments may be more substantial because the number of experiments for MOX are fewer (vs. LEU); therefore, it may be more difficult to properly consider these differences and assign a bias value. The review considers the information and guidance in Appendix D to this SRP regarding available MOX benchmark experiments and their important characteristics and how to select appropriate benchmark experiments and how to determine a conservative bias from the benchmark analysis.

- The materials review evaluates the material properties of the packaging components. Important considerations include the material properties of closure components (e.g., seals, bolts) of the containment vessel(s) and the outer packaging. The review ensures these components have the required strength and other properties under normal conditions of transport and hypothetical accident conditions. This includes resistance to conditions such as stress-corrosion cracking; differences in thermal expansion (bolts vs. bolted items); chemical, galvanic, or other reactions among materials; and radiation effects. Other important considerations include the material properties of any gamma and neutron shields and any neutron poisons that are present in the package under normal conditions of transport and hypothetical accident conditions. The review should identify any undesirable conditions. Powder contents with high moisture content are particularly susceptible to gas generation due to radiolysis.

- The review of operating procedures confirms that the containment vessel(s) has been properly closed and its closure bolts are properly tightened to the specified torque values, and that an appropriate pre-shipment leak test is performed.

- The review of the acceptance tests and the maintenance program verifies that appropriate fabrication, maintenance, and periodic verification leakage tests are performed. This includes appropriate fabrication leak tests and maintenance actions (e.g., checks of seal condition, seal replacement, testing of new seals), with acceptance criteria and requirements that are consistent with those identified in the confinement review.

- The review of the acceptance tests and the maintenance program also verifies that gamma shielding, neutron shielding, and neutron poisons, if any, are present and are subject to appropriate acceptance tests and maintenance actions to ensure they are fabricated and maintained to meet the design and regulatory requirements. For neutron poisons, this includes acceptance and qualification tests to ensure and verify the poison properties meet the minimum required specifications (e.g., minimum boron-10 concentration and uniformity).

A.9.6 Reference

Regulatory Guide 7.11, U.S. Nuclear Regulatory Commission, “Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m),” ADAMS Accession No. ML003739413.

A.10 Unirradiated Mixed Oxide Fuel Packages

A.10.1 Purpose of Package

The purpose of this type of package is to transport unirradiated MOX fuel assemblies and individual MOX fuel rods. These packages are also referred to as “MOX fresh fuel packages.”

This appendix addresses those packages in which the contents are Type B quantities of fissile MOX material. Because of the greater radiological hazard from MOX (vs. LEU), MOX requires shipment in a Type B package. The fissile MOX material can be in an entire assembly or as individual fuel rods.

A.10.2 Description of a Typical Package

A typical packaging consists of a metal outer shell, closed with bolts and elastomeric seals, and an impact-limiter system. An internal steel strongback, shock-mounted to the outer shell, supports one or more fuel assemblies, which are fixed in position on the strongback by clamps, separator blocks, and end support plates. Depending on the type of fuel, neutron poisons may be used to reduce reactivity. Material surrounding the contents could be employed to shield against neutrons and/or gammas. If the package is used to transport individual fuel rods, a separate inner container is often employed.

The contents of the package are unirradiated MOX in fuel assemblies or individual fuel rods. Because the majority of these packages are for commercial reactor fuel, the MOX is typically in the form of Zircaloy-clad plutonium-uranium dioxide pellets.

A sketch of the typical package described above is shown in Figure A.10-1.

A.10.3 Alternative Package Design

In an alternative design for a MOX fresh fuel package, the fuel assemblies are fixed in position by two or three steel channels, mounted by angle irons or a similar bracing structure to a thin-walled inner metal container. This inner container is in turn surrounded by a honeycomb material and enclosed in a metal outer shell. Foam cushioning material can be used to cushion the fuel assemblies and may be used between the inner and outer container.

A.10.4 Package Safety

Safety Functions

The principal functions of the package are to provide containment, shielding, and criticality safety. Package design features that accomplish the containment and criticality functions might also provide adequate shielding to satisfy the requirements for nonexclusive-use shipment. Additional shielding may be required if significant quantities of certain isotopes [e.g., plutonium-236, plutonium-238, plutonium-241, or americium-241 (from the decay of plutonium-241)] are present in the MOX material.

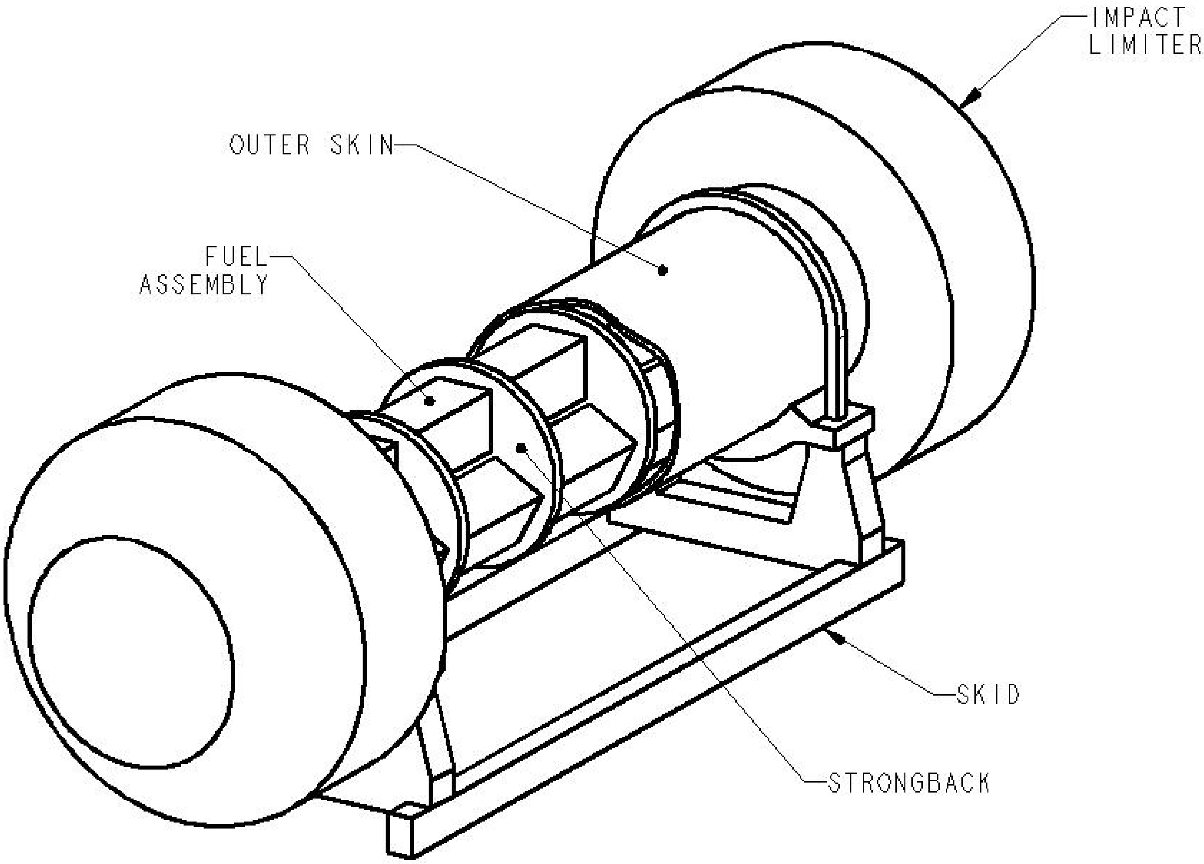

Figure A.10-1 Sketch of the typical MOX fresh fuel package

<u>Safety Features</u>

- Impact limiters protect the outer shell and contents under hypothetical accident conditions. They also provide thermal insulation for the O-ring seals of the outer shell.

- A strongback with end-support plates, clamps, and separators maintains the fuel assemblies in a fixed position relative to each other and to any neutron poisons.

- The metal outer shell of the packaging retains and protects the fuel assemblies and may provide a minimum spacing between assemblies in an array of packages and provide some attenuation to satisfy the shielding requirements.

- Neutron poisons, if present, reduce reactivity and can provide some neutron shielding.

- The metal outer shell also provides containment of the radioactive material.

A.10.5 Typical Areas of Review for Package Drawings

- outer shell (containment vessel body)

  — material specifications
  — dimensions and tolerances

- fabrication codes and standards
    - weld specifications, including codes or standards for nondestructive examination

- outer shell closure (containment vessel closure)

    - lid materials, dimensions, and tolerances
    - bolt specifications, including number, size, and torque
    - seal material, size, and compression specifications
    - seal groove dimensions
    - leak-test ports
    - applicable codes and standards

- structural components (e.g., strongback, support plates, fuel clamps, separators) that fix the position of fuel assemblies or relative position between fuel assemblies and poisons

    - dimensions, tolerances, and material specifications
    - methods of attachment
    - applicable engineering codes or standards

- thermal insulating/impact absorbing and/or shielding material

    - type and (material) specifications
    - dimensions and tolerances
    - density

- neutron poisons

    - dimensions and tolerances
    - minimum poison content
    - location and method of attachment
    - material specifications
    - applicable codes and standards

- moderating materials, including plastics, wood, and foam

    - location
    - material properties

Drawings should include reasonably lenient dimensional tolerances for the packaging components to allow practical fabrication variability. For example, the outer length of the container may vary without affecting the package's performance. Dimensions that are important with respect to criticality safety should be strictly limited. For example, the separation distance provided by certain structural features (e.g., clamps, spacers) may be important for criticality safety, and those features should be identified with close tolerances.

A.10.6 Typical Areas of Safety Review

- The general information review identifies the fuel assembly designs authorized in the package, including the following:

    - number of and arrangement of fuel assemblies

    - number, pitch, dimensions (with tolerances), and position of fuel rods, guide tubes, water rods, and channels
    - material specifications of the cladding, guide tubes, water rods, and channels
    - overall assembly dimensions, including active fuel length
    - authorization or restrictions on missing fuel rods or partial-length rods
    - maximum amount of fissile material
    - pellet dimensions and tolerances
    - minimum cladding thickness
    - fuel-clad gap and fill gas
    - type, location, and concentration of burnable poisons, and other types of poisons
    - type, location, and quantity of plastics, such as polyethylene, within or surrounding the fuel assemblies

- The review considers the characteristics of MOX materials described in Appendix B to this SRP for shielding and thermal reviews. This includes the higher specific content decay heat rate (vs. LEU material) for the thermal review and the need to evaluate the radiation-source term as for other Type B packages (e.g., spent nuclear fuel, others) for the shielding review.

- The structural and thermal reviews evaluate the performance of the containment system under both normal conditions of transport and hypothetical accident conditions, particularly the drop, crush (if needed), and puncture tests. Primary emphasis is on the structural integrity of the outer shell (containment vessel) and its closure, and on the thermal performance of the elastomeric seals. If the impact limiters provide thermal protection for the seals, the structural review also confirms the structural integrity of the impact limiters.

- The structural review addresses possible damage to the impact limiters, outer shell, strongback, fuel assembly, neutron poisons (if present), clamps, separators, and end support plates to ensure that the fuel assemblies and neutron poisons are maintained in a fixed position relative to each other under hypothetical accident conditions.

- The criticality reviewer will consult with the structural and thermal reviewers on the minimum spacing between fuel assemblies in different packages in an array under hypothetical accident conditions. Spacing can be affected by separation of the strongback from its shock mounts, failure of the shock mounts or fuel-assembly clamps, and deformation of the outer shell of the package. Damage to the outer shell and charring of any thermal insulating/impact absorbing material (if present) may result in closer spacing than that of normal conditions of transport.

- The thermal review evaluates the effect of the fire on outer-shell O-ring seals, neutron poisons, plastic sheeting, thermal insulation material (if present), or other temperature-sensitive materials under hypothetical accident conditions.

- The thermal review evaluates the fuel/cladding temperatures, along with the temperatures of packaging components relied on for structural, containment, shielding, or criticality design and performance. This evaluation is to confirm limits are met and to ensure cladding and package component performance for normal conditions of transport and hypothetical accident conditions. Fuel rod and assembly temperatures can be evaluated with temperature-sensing devices placed on the basket and fuel rods.

- The thermal review evaluates the maximum normal operating pressure when the package is subjected to the heated condition for 1 year, accounting for all sources of gases (e.g., those present in the package at the time of closure, fill gas released from rods). The review also evaluates the thermal gradients through the fuel/clad and package components.

- The thermal review, for hypothetical accident conditions, (i) evaluates the package at the maximum heat load of the contents unless a lower value is more unfavorable and (ii) evaluates the package pressures, considering possible gas increases (e.g., from an unlikely fuel rod failure).

- The containment review evaluates the containment design criteria to ensure (1i) they are appropriately and correctly applied to the containment system, and (ii) they are supported by calculations that demonstrate the package meets the regulatory limits for releases. The reviewer should verify that the applicant has justified the releasable source terms in the calculations.

- The shielding review evaluates the ability of the package to satisfy the allowed radiation levels during both normal conditions of transport and hypothetical accident conditions.

- The shielding review evaluates the radiation-source terms for appropriate consideration of contributing aspects of the contents. This includes accounting for plutonium-236, plutonium-238, plutonium-239, plutonium-240, plutonium-241, plutonium-242, and americium-241 (from plutonium-241 decay) when these nuclides are present in the contents for their contributions to the gamma- and neutron-source terms. This also includes ensuring consideration of (α, n) reactions, spontaneous fission, neutron multiplication contributions to the neutron source, and definition of an appropriate energy structure of the neutron source. Appendix B to this SRP describes different gamma and neutron emission rates for various transuranic elements and MOX with different grades of plutonium.

- The criticality review addresses both normal conditions of transport and hypothetical accident conditions. Key areas for this review include the following:

  — The number of packages in the array and the array configuration (e.g., pitch, orientation of packages): Because of movement of the strongback within the package and the location of poisons, the arrays might not be symmetrical.

  — Degree of moderation: Structural features, as well as packaging material such as plastic sheeting, are evaluated for the possibility of preferential flooding within the package. Plastic sheeting on the fuel assemblies should be open at both ends to preclude preferential flooding. Flooding between the fuel pellets and cladding is also considered. Variations in the allowable amount of lightweight packaging material and plastic shims inserted in the fuel assemblies can also affect criticality under normal conditions of transport.

- For the criticality review, the differences between the package and benchmark experiments may be more substantial because the number of experiments for MOX are fewer (vs. LEU); therefore, it may be more difficult to properly consider these differences and assign a bias value. The review considers the information and guidance in Appendix D to this SRP regarding available MOX benchmark experiments and their important characteristics and how to select appropriate benchmark experiments and determine a conservative bias from the benchmark analysis.

- The materials review evaluates the material properties of the packaging components. Important considerations include the material properties of closure components (e.g., seals, bolts) of the containment vessel(s) and the outer packaging. The review ensures these components have the required strength and other properties under normal conditions of transport and hypothetical accident conditions. This includes resistance to conditions such as stress-corrosion cracking; differences in thermal expansion (bolts vs. bolted items); chemical, galvanic, or other reactions among materials; and radiation effects. Other important considerations include the material properties of any gamma and neutron shields and any neutron poisons that are present in the package under normal conditions of transport and hypothetical accident conditions. The review should identify any undesirable conditions. Powder contents with high moisture content are particularly susceptible to gas generation due to radiolysis.

- The review of operating procedures ensures that instructions are provided so that proper clamps, separators, and poisons are selected for the type of fuel assemblies to be shipped and that these items are properly installed prior to shipment. The procedures should also address any other restrictions (e.g., limits on number of shims and plastic wrappers to limit total polyethylene content) considered in the package evaluation. The review also confirms that instructions are provided for the proper closure of the outer shell and for the proper completion of pre-shipment leak test.

- The review of the acceptance tests and the maintenance program also verifies that gamma shielding, neutron shielding, and neutron poisons, if any, are present and are subject to appropriate acceptance tests and maintenance actions to ensure they are fabricated and maintained to meet the design and regulatory requirements. For neutron poisons, this includes acceptance and qualification tests to ensure and verify the poison properties meet the minimum required specifications (e.g., minimum boron-10 concentration and uniformity). The review also verifies that appropriate fabrication, maintenance, and periodic verification leakage tests of the outer shell are performed with acceptance criteria and requirements that are consistent with those identified in the confinement review.