December 2021

Revision 21A

OPTIMUS®-H

(OPTImal Modular Universal Shipping Cask)

SAFETY ANALYSIS REPORT

INITIAL SUBMITTAL

NON-PROPRIETARY VERSION

Docket No. 71-9392

NAC INTERNATIONAL

Atlanta Corporate Headquarters: 3930 East Jones Bridge Road, Peachtree Corners, Georgia 30092 USA Phone 770-447-1144, Fax 770-447-1797, www.nacintl.com

Enclosure 1

List of Effective Pages and SAR

NAC OPTIMUS®-H SAR, Revision 21A

(Docket No 71-9392)

NAC International

December 2021

December 2021

Revision 21A

OPTIMUS®-H

(OPTImal Modular Universal Shipping Cask)

SAFETY ANALYSIS REPORT

NON-PROPRIETARY VERSION

Docket No. 71-9392

NAC INTERNATIONAL

Atlanta Corporate Headquarters: 3930 East Jones Bridge Road, Peachtree Corners, Georgia
30092 USA Phone 770-447-1144, Fax 770-447-1797, www.nacintl.com

This page intentionally left blank

List of Effective Pages

Chapter 1
Page 1-i thru 1-ii ..... Revision 21A
Page 1-1 ..... Revision 21A
Page 1.1-1 thru 1.1-2..... Revision 21A
Page 1.2-1 thru 1.2-19..... Revision 21A
Page 1.3-1 thru 1.3-3..... Revision 21A

12 drawings (see Section 1.3)

Chapter 2
Page 2-i thru 2-vi ..... Revision 21A
Page 2-1 ..... Revision 21A
Page 2.1-1 thru 2.1-22..... Revision 21A
Page 2.2-1 thru 2.2-11..... Revision 21A
Page 2.3-1 thru 2.3-5..... Revision 21A
Page 2.4-1 ..... Revision 21A
Page 2.5-1 thru 2.5-7..... Revision 21A
Page 2.6-1 thru 2.6-39..... Revision 21A
Page 2.7-1 thru 2.7-48..... Revision 21A
Page 2.8-1 ..... Revision 21A
Page 2.9-1 ..... Revision 21A
Page 2.10-1 ..... Revision 21A
Page 2.11-1 ..... Revision 21A
Page 2.12-1 thru 2.12-20... Revision 21A

Chapter 3
Page 3-i thru 3-iii ..... Revision 21A
Page 3-1 ..... Revision 21A
Page 3.1-1 thru 3.1-6..... Revision 21A
Page 3.2-1 thru 3.2-5..... Revision 21A
Page 3.3-1 thru 3.3-35..... Revision 21A
Page 3.4-1 thru 3.4-24..... Revision 21A
Page 3.5-1 thru 3.5-13..... Revision 21A

Chapter 4
Page 4-i thru 4-ii ..... Revision 21A
Page 4-1 ..... Revision 21A
Page 4.1-1 thru 4.1-3..... Revision 21A
Page 4.2-1 ..... Revision 21A
Page 4.3-1 ..... Revision 21A
Page 4.4-1 ..... Revision 21A
Page 4.5-1 thru 4.5-58..... Revision 21A

Chapter 5
Page 5-i thru 5-iii ..... Revision 21A
Page 5-1 ..... Revision 21A
Page 5.1-1 thru 5.1-5..... Revision 21A
Page 5.2-1 thru 5.2-4..... Revision 21A
Page 5.3-1 thru 5.3-10..... Revision 21A
Page 5.4-1 thru 5.4-19..... Revision 21A
Page 5.5-1 thru 5.5-30..... Revision 21A

Chapter 6
Page 6-i thru 6-iv ..... Revision 21A
Page 6-1 ..... Revision 21A
Page 6.1-1 thru 6.1-3..... Revision 21A
Page 6.2-1 thru 6.2-4..... Revision 21A
Page 6.3-1 thru 6.3-19..... Revision 21A
Page 6.4-1 thru 6.4-14..... Revision 21A
Page 6.5-1 ..... Revision 21A
Page 6.6-1 thru 6.6-20..... Revision 21A
Page 6.7-1 ..... Revision 21A
Page 6.8-1 thru 6.8-22..... Revision 21A
Page 6.9-1 thru 6.9-2..... Revision 21A

Chapter 7
Page 7-i thru 7-ii ..... Revision 21A
Page 7-1 thru 7-3..... Revision 21A
Page 7.1-1 thru 7.1-8..... Revision 21A
Page 7.2-1 thru 7.2-3..... Revision 21A
Page 7.3-1 thru 7.3-4..... Revision 21A
Page 7.4-1 ..... Revision 21A
Page 7.5-1 thru 7.5-66..... Revision 21A

Chapter 8
Page 8-i thru 8-ii ..... Revision 21A
Page 8-1 ..... Revision 21A
Page 8.1-1 thru 8.1-6..... Revision 21A
Page 8.2-1 thru 8.2-8..... Revision 21A
Page 8.3-1 ..... Revision 21A

This page intentionally left blank

Chapter 1
General Information

Table of Contents

1 GENERAL INFORMATION 1-1

1.1 Introduction 1.1-1

1.2 Package Description 1.2-1
1.2.1 Packaging 1.2-1
1.2.2 Radioactive Contents 1.2-8
1.2.3 Special Requirements for Plutonium 1.2-12
1.2.4 Operational Features 1.2-12

1.3 Appendix 1.3-1
1.3.1 References 1.3-1
1.3.2 Glossary of Terms and Acronyms 1.3-2
1.3.3 Packaging General Arrangement Drawings 1.3-3

List of Figures

Figure 1-1 OPTIMUS®-H Packaging 1.1-2
Figure 1-2 CCV Packaging Components 1.2-16
Figure 1-3 OSV Packaging Components 1.2-17
Figure 1-4 Impact Limiter Packaging Components 1.2-18
Figure 1-5 Packaging Containment System 1.2-19

List of Tables

Table 1-1 Content Designations 1.2-13
Table 1-2 TRU Waste FGE Limits 1.2-13
Table 1-3 IFW FME Limits 1.2-14
Table 1-4 TRU Waste and IFW Activity Limits for Key Isotopes 1.2-15

1 GENERAL INFORMATION

This chapter of the Safety Analysis Report (SAR) presents a general introduction to, and description of, the OPTImal Modular Universal Shipping cask for High activity contents (OPTIMUS®-H). A cut-away schematic of the packaging is shown in Figure 1-1. Descriptions of the packaging, including the packaging features, contents, and operational features, are presented in Section 1.2. A glossary of the general terminology and acronyms used throughout this SAR is presented in Appendix 1.3.2. The packaging General Arrangement Drawings are included in Appendix 1.3.3.

As demonstrated by this SAR, the OPTIMUS®-H package satisfies the regulatory requirements of the United States Nuclear Regulatory Commission (NRC) regulations, namely Title 10, Part 71 of the Code of Federal Regulations (10 CFR 71).

This page intentionally left blank.

1.1 Introduction

Model No. OPTIMUS®-H is designated as Type B(U)F-96 per 10 CFR 71.4. The package radioactive contents include Type B quantities of normal form Transuranic (TRU) waste and Irradiated Fuel Waste (IFW) contents. The package is designed to be transported by highway, rail and sea. The consignor must ship the package with IFW contents under exclusive use controls. However, a package with TRU waste contents may be shipped on a nonexclusive use conveyance or under exclusive use controls. The Maximum Normal Operating Pressure (MNOP) of the package is 100 psig (690 kPa).

The package criticality safety index (CSI) is 0.0. Per 10 CFR 71.59(b), the (CSI) may be zero if an unlimited number of packages is subcritical, with the value of "N" effectively equal to infinity.

The packaging, described in greater detail in Section 1.2.1, consists of three (3) main components; a Cask Containment Vessel (CCV), an Outer Shield Vessel (OSV), and an Impact Limiter System (ILS), as shown in Figure 1-1. The CCV is a stainless steel vessel with a bolted closure designed to the leak-tight containment in accordance with the criterion of ANSI N14.5-2014 [1-1]. The OSV is a thick-walled ductile cast iron vessel with a bolted lid containing the CCV during transport and protecting it from the direct effects of impact loading. The OSV also protects the CCV from the direct effects of the fire during the HAC thermal test. The ILS consist of two (2) identical foam-filled impact limiters attached to upper and lower ends of the OSV. The impact limiters are designed to crush and absorb the impact energy when subjected to NCT free drop and HAC free drop tests, thereby limiting the loads imparted to the OSV and CCV. The impact limiters also insulate the upper and lower ends of the OSV and CCV from the direct effects of the fire during the HAC thermal test.

The package is configured with an Shield Insert Assembly (SIA) inside the CCV for radioactive contents requiring additional shielding to demonstrate compliance with dose rate limits. [redacted] The SIA is a painted carbon steel container consisting of a body and lid fully encasing the radioactive contents to provide additional shielding. [redacted]

This SAR demonstrates the packaging meets the applicable requirements of 10 CFR 71. The basis for qualification is the safety analysis contained herein. The package is shown to comply with the external temperature limits of 10 CFR 71.43(g) and external radiation standards of 10 CFR 71.47(b), 10 CFR 71.51(a)(1) and 10 CFR 71.51(a)(2).

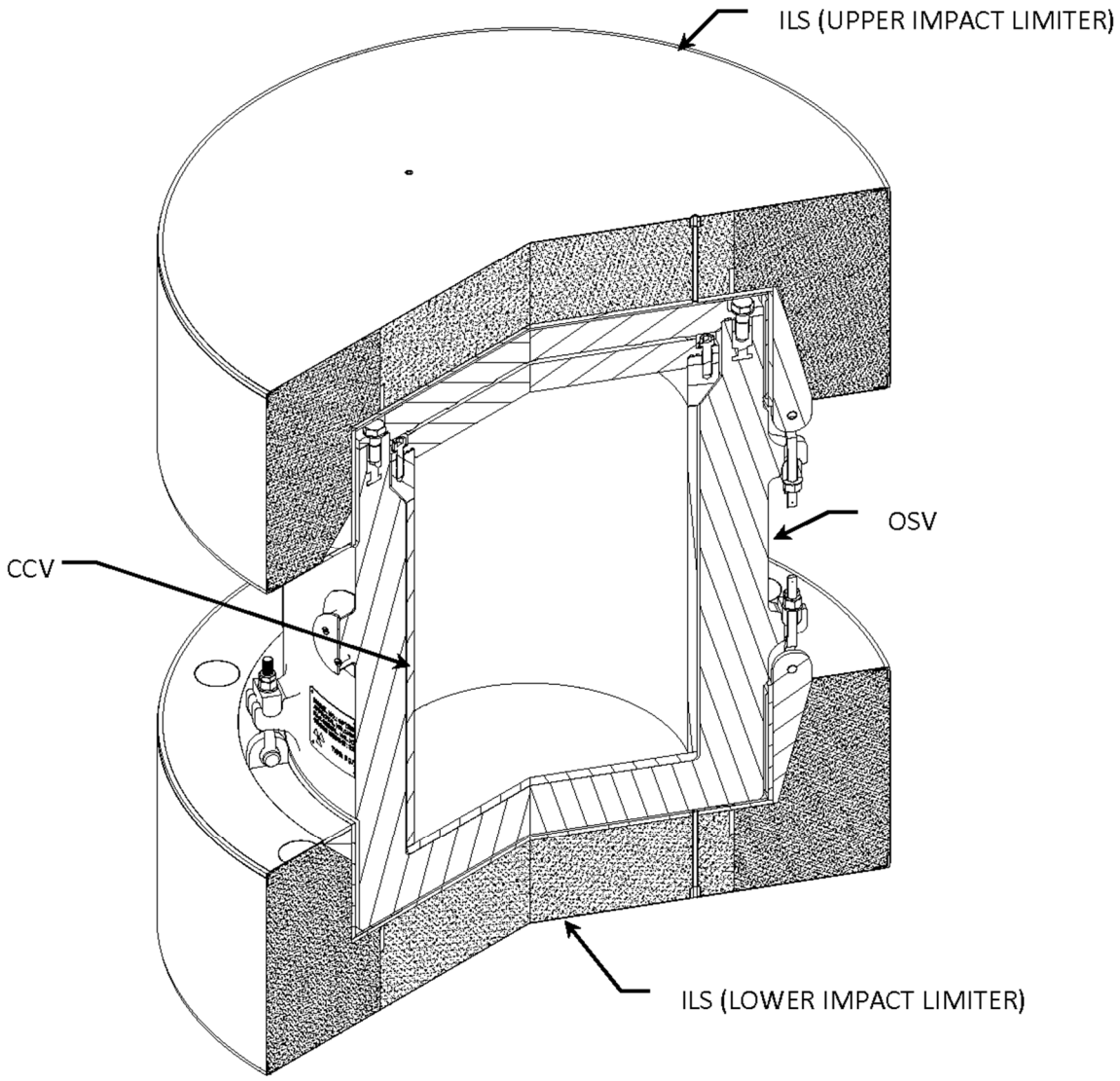


Figure 1-1 OPTIMUS®-H Packaging

1.2 Package Description

1.2.1 Packaging

The OPTIMUS®-H packaging consists of a Cask Containment Vessel (CCV), an Outer Shield Vessel (OSV), and upper and lower impact limiters, together referred to as the Impact Limiter System (ILS). The CCV fits within the cavity of the OSV and the upper and lower impact limiters are attached to the respective ends of the OSV. A cut-away view of the assembled packaging is shown in Figure 1-1. The packaging may also be configured with a Shield Insert Assembly (SIA) within the cavity of the CCV to provide additional shielding when required to demonstrate compliance of the contents with regulatory dose rate limits, as discussed in Attachment 7.5-1.

The CCV is the packaging containment system. It is a stainless steel cylindrical vessel that includes a body weldment, bolted lid, bolted port cover, and O-ring seals. An expanded view of the CCV assembly is shown in Figure 1-2. The CCV lid includes a port used for inerting the CCV cavity and contents. A bolt port cover is used to seal the CCV port during transport. The CCV closure devices are discussed further in Section 1.2.1.4, *Packaging Closure Devices*.

The OSV is a ductile cast iron vessel consisting of a body and lid. An expanded view of the OSV assembly is shown in Figure 1-3. The OSV closure devices are discussed further in Section 1.2.1.4, *Packaging Closure Devices*.

The packaging is protected during transport by cylindrical-shaped impact limiters fitting over the upper and lower ends of the OSV assembly. The designs of the upper and lower impact limiters are identical.

[redacted] They consist of energy-absorbing closed-cell polyurethane foam cores sealed inside the exterior stainless steel inner and outer shells, as shown in Figure 1-4. The impact limiters are discussed further in Section 1.2.1.4, *Energy-Absorbing Features*.

[redacted]

The SIA is a coated carbon steel container placed inside the CCV cavity to provide supplemental gamma shielding. [redacted]

The SIA is also not relied upon for thermal or containment functions. Although no structural credit is taken for the SIA in the structural evaluation of the other packaging components, the SIA is designed to withstand the most severe regulatory tests (e.g., free drop) without structural failure, such that shielding integrity is maintained for those conditions in which the SIA is credited in the shielding evaluation.

The following sections discuss the overall dimensions and weight of the package, the containment, shielding, criticality control, structural, and heat transfer features of the packaging, as well as the packaging marking and coolants.

General arrangement drawings showing the packaging dimensions and materials of construction are included in Appendix 1.3.3.

See Section 2.1.4 “Identification of Codes and Standards for Packaging” for the codes and standards used for package design, materials specification, fabrication, welding, and inspection.

1.2.1.1 Overall Dimensions

The OPTIMUS®-H packaging has outer diameter of 74.2-inch (188 cm) and an overall height of 83.2-inch (211 cm), which are both greater than the minimum package dimension of 10 cm required by 10 CFR 71.43(a).

1.2.1.2 Package Weight

The gross weight of the package, including the maximum CCV content weight, is 32,000 pounds (14,512 kg) or less.

1.2.1.3 Maximum Normal Operating Pressure (MNOP)

The Maximum Normal Operating Pressure (MNOP) of the package, as defined in 10 CFR 71.4, is 100 psig (690 kPa).

1.2.1.4 Structural Features

The structural features of the packaging are summarized in this section. A more detailed discussion of the packaging structural features is provided in Chapter 2.

Lifting and Tiedown Devices

The OSV has two diametrically-opposed trunnions or four (4) tiedown lugs that can all function as the lifting and tie-down devices, as shown in Figure 1-3. The OSV trunnions and tiedown lugs are structural parts of the packaging and are analyzed accordingly in Chapter 2.

Energy-Absorbing Features

The packaging is equipped with cylindrical-shaped impact limiters, shown in Figure 1-4, that fit over the ends of the OSV assembly [redacted] The impact limiters are designed to crush and absorb energy under NCT and HAC free drops to limit the shock loads imparted to the OSV, CCV and its contents.

The impact limiters are constructed from stainless steel shells completely encasing energy-absorbing closed-cell polyurethane foam core components to create a sealed cavity to protect the foam core from the external environment. The impact limiter inner stainless steel weldment is a robust structure [redacted]

[redacted]

Internal Supports or Positioning Features

Shoring must be placed between loose fitting radioactive contents and the CCV cavity to prevent excessive movement during transport. The shoring may be made from any material that does not significantly off-gas and is not reactive with the packaging materials or contents, such as dry wood or metal. Shoring materials should also have a melting temperature above 300°F (149°C) to ensure shoring maintains its geometry under routine and normal conditions of transport. When shipping TRU waste contents that contain non-compliant items (i.e., content types 1-2A, 1-2B or 1-2C) in secondary containers (e.g., drums or boxes), the displaced volume of the shoring is limited to 2.0 ft^3 (56 L).

Outer Packaging

The OSV is the thick-walled non-pressure-retaining outer packaging housing the CCV and protects it from external loading, such as free drop impacts. As shown in Figure 1-3, the OSV consists of a body and closure lid, each made from monolithic castings of ductile iron. [redacted] When installed, the inner portion of the OSV lid is recessed inside the top end of the OSV body bolt flange. The tight fit between the OSV lid and body at this interface provide shear relief for the OSV closure bolts. The OSV cavity is sized to provide sufficient clearance to permit free differential thermal expansion of the CCV under all NCT and HAC conditions. The OSV also include a drain port, with no any intended safety function during transport.

Packaging Closure Devices

The packaging closure devices include the bolted CCV lid, the bolted CCV port cover, and the bolted OSV lid. The primary safety function of the CCV lid and CCV port cover is containment, but the OSV lid is not part of containment boundary.

The CCV lid, shown in Figure 1-2, is a circular plate secured to the CCV body by [redacted] CCV lid bolts and sealed by an elastomeric O-ring. [redacted]

[redacted].

During transport of the CCV port is plugged by the CCV port cover and sealed by an elastomeric O-ring. The CCV port cover is secured to the CCV lid [redacted] The CCV port cover is recessed in a pocket within the CCV lid and protected from shear loading due to free drop and puncture tests.

The OSV lid, shown in Figure 1-3, [redacted]

1.2.1.5 Secondary Packaging Components

As discussed in Section 1.2.2.1, radioactive contents are packaged in secondary containers (e.g., drums, liners, specialty bags, etc.) to prevent direct contact between the contents and packaging to minimize the spread of contamination and to facilitate content loading and unloading operations. In addition, shoring may be used to prevent significant movement of the radioactive contents within the CCV during transportation. Secondary packaging components are not considered licensed components, but must be made from materials that do not adversely react with the packaging or component materials. Secondary containers may be any shape or size that fits within the cavity of the CCV. Each secondary container and each confinement boundary of the contents must have one or more venting mechanisms (e.g., filter, vent, permeable membrane, etc.) that satisfies the minimum hydrogen diffusivity rates in Table 4.5-4 to allow gases to readily flow into or out of each confinement region of the CCV and contents. The hydrogen diffusivity rate of each venting mechanism shall be based on available product literature, published industry-accepted data, or test data, otherwise the minimum rates from Table 4.5-4 shall be assumed.

1.2.1.6 Internal Support Components

Not applicable.

1.2.1.7 Tamper-Indicating Features

The OPTIMUS®-H packaging has tamper indicating devices that are attached to the upper and lower impact limiters, as shown on general arrangement drawing 70000.14-501 in Appendix 1.3.3, to meet the requirement for tamper-indicating features as specified in 10 CFR 71.43(b). See Section 2.4.2 for more details.

1.2.1.8 Packaging Markings

The packaging marking is included on a nameplate that is permanently affixed to the exposed exterior surface of the OSV body, as shown on general arrangement drawing 70000.14-501 in Appendix 1.3.3. At a minimum, the nameplate includes the package model number, approval number, serial number, gross weight, trefoil symbol, and package type.

1.2.1.9 Codes and Standards

The codes and standards used for the packaging design, material specifications, fabrication, welding, and inspection are described throughout the SAR and summarized in this section. As discussed in Section 2.1.4, the package is designed, fabricated, tested, and maintained in accordance with codes and standards that are appropriate for transportation packages with Category I container contents. Accordingly, the codes and standards used are based on Regulatory Guide 7.6 [1-2] and NUREG/CR-3854 [1-3].

The package containment system is designed in accordance with the applicable requirements of the ASME Code, Section III, Division 1, Subsection NB [1-4]. The non-containment structural components of the packaging are designed in accordance with the applicable allowable stress design criteria for plate- and shell-type Class 2 supports from the ASME Code, Section III, Division 1, Subsection NF [1-5]. However, the energy-absorbing foam materials used in the impact limiters and the ductile cast iron components of the OSV are fabricated, installed, and tested in accordance with the applicable standard industry practices. Further discussion of the codes and standards used for the structural design of the packaging is provided in Section 2.1.4. Discussion of the codes and standards used for the fabrication, welding, and examination of the packaging is provided in Section 2.3.

1.2.1.10 Heat Transfer Features

The special heat transfer features of the packaging are discussed in this section. They include the impact limiters. A more detailed discussion of the package heat transfer features is provided in Chapter 3.

The upper and lower impact limiters insulate the ends of the package from the direct effects of the HAC fire and prevent the elastomeric containment O-ring seals from exceeding the material temperature limit. [redacted]

The package does not rely upon any active cooling systems.

1.2.1.11 Containment Features

The packaging has a simple, robust containment system design. Containment of radioactive material for the packaging is provided by the Cask Containment Vessel (CCV). Other than the CCV lid closure and port cover closure, there are no penetrations to the containment system, and no valves or pressure relief devices of any kind. The packaging does not rely on any filter or mechanical cooling system to meet containment requirements, nor does it include any vents or valves that allow for continuous venting.

The CCV is comprised of a body weldment, bolted closure lid, bolted port cover, and the associated lid and port cover containment O-ring seals. A sketch of the CCV is included in Figure 1-5, with the pressure-retaining boundary is outlined in red. The top view is simplified to only show the components significant to the containment system, removing details such as test ports, lifting hoist ring locations, and alignment pins.

The CCV port cover, which fits flush into the port opening of the CCV lid, is a solid austenitic stainless steel [redacted] plate with machined bolt holes, two (2) concentric O-ring groove, two (2) O-ring test ports. [redacted]

The CCV is designed, fabricated, examined, tested, and inspected in accordance with the applicable requirements of of the ASME Code with certain exceptions discussed in Chapter 2. A detailed description of the containment system is provided in Section 4.1.

1.2.1.12 Neutron and Gamma Shielding Features

Gamma shielding on the side and bottom end of the packaging is provided by stainless steel plates forming the CCV cylindrical shell and bottom plate plus the thick shell and bottom plate of the OSV body. [redacted] The top and bottom ends of the packaging are also shielded by the impact limiters attached to the ends of the OSV assembly.

When required to demonstrate compliance with regulatory dose rate limits, that packaging is configured with an SIA. [redacted]

Neutron shielding is not necessary for the specified radioactive contents.

1.2.1.13 Criticality Control Features

Neutron absorbers for criticality control are not necessary for the specified radioactive contents.

1.2.2 Radioactive Contents

The acceptable radioactive contents of the package include two (2) classes of waste; TRU waste and irradiated fuel waste (IFW) as summarized in Table 1-1, and assigned unique Content IDs

used throughout the SAR for clarity and consistency. The acceptable radioactive contents are discussed further in the following sections.

1.2.2.1 TRU Waste

TRU waste is classified as intermediate-level radioactive waste exposed to alpha radiation, or contains long-lived radionuclides in concentrations requiring isolation and containment for periods beyond several hundred years. It typically requires shielding during handling and interim storage. This type of waste includes refurbishment waste, ion-exchange resins and some radioactive sources used in radiation therapy.

TRU waste contents are divided into two types; compliant[a] TRU waste (Content 1-1) and non-compliant TRU waste (Content 1-2). Acceptable non-compliant TRU waste is subdivided into three (3) sub-types of TRU waste drums; those containing aerosol cans with compressed gas propellant (Content 1-2A), those containing aerosol cans with liquified gas propellant or unknown propellants (Content 1-2B), and those containing standard DOT 3E lecture bottles (Content 1-2C). Each package prepared for shipment may only contain one (1) form of non-compliant TRU waste contents and shall otherwise satisfy the Waste Isolation Pilot Plant (WIPP) Waste Acceptance Criteria (WAC).

The quantity of non-compliant TRU waste items permitted in the contents is limited to assure the CCV internal pressure does not exceed the design internal pressure loads for NCT and HAC and to prevent combustible gas mixtures. It conservatively assumes all aerosol cans or Standard DOT 3E Lecture bottles are ruptured. The non-compliant TRU waste content limits determined in Chapter 4 are as follows:

- Content 1-2A: A maximum of ninety-five (95) standard DOT 2P or 2Q 1-liter aerosol cans full of compressed gas propellant.
- Content 1-2B: A maximum of 4.4 liters of liquified gas propellant when the volume is known based on process knowledge x-ray (or other) interrogation methods, or a maximum of four (4) full standard DOT 2P or 2Q 1-liter aerosol cans if the amount of liquified propellant, or type of propellant, in the aerosol cans is not known.
- Content 1-2C: A maximum of eight (8) full Standard DOT 3E Lecture bottles with known contents of non-flammable gases, or a maximum of one (1) Standard DOT 3E Lecture bottle with unknow contents.

[a] Compliant TRU waste is TRU waste meeting the Waste Acceptance Criteria (WAC) for the Waste Isolation Pilot Project (WIPP).

TRU waste shall meet the following requirements and restrictions.

Type and Form of TRU Waste Material:

1. Byproduct, source, special nuclear material, non-fissile or fissile-excepted, as special form or non-special form in the form of process solids or resins, either dewatered, solid, or solidified waste; or
2. Dewatered, solid, or solidified transuranic-containing wastes (TRU), fissile, non-fissile, or fissile-excepted; or
3. Neutron activated metals or metal oxides in solid form, including reactor components or segments of components of waste from a nuclear process or power plant.

Maximum Quantity of TRU Contents per Package:

1. That quantity of any radioactive material not generating spontaneously more than 200 thermal watts of radioactive decay heat.
2. TRU waste not exceeding the fissile gram equivalents (FGE) of fissile radioactive material in Table 1-2 for the specified criticality configuration limits.
3. TRU waste contents shall comply with regulatory dose rate limits, as determined in accordance with Chapter 7, Attachment 7.5-1. Note: Maximum activity limits for key individual gamma-emitting isotopes (e.g., Co-60, Cs-137 and Ba-137m) and neutron-emitting isotopes (e.g., Cf-252 and Cm-244) are provided in Table 1-4.

Loading and Shipping Restrictions:

1. TRU waste contents shall may be shipped on a nonexclusive use conveyance or under exclusive use controls.
2. TRU waste contents shall be in secondary containers (e.g., drums or boxes).
3. TRU waste contents with a total decay heat exceeding 50 watts shall be inerted with helium gas per Attachment 7.5-2.
4. Compliance with the flammable gas concentration limits shall be demonstrated using the procedure described in Attachment 7.5-3.
5. Explosives, corrosives, non-radioactive pyrophorics, and sealed items containing compressed and/or flammable gas (e.g., aerosol cans, lecture bottles, etc.) are prohibited. Pyrophoric radionuclides may be present only in residual amounts less than 1 wt%. All nonradioactive pyrophoric material be reacted (or oxidized) and/or otherwise rendered nonreactive prior to placement in a secondary container (e.g., drum).

6. Free liquids shall not exceed 1% of the CCV cavity volume.
7. Maximum weight of CCV contents, including TRU waste in a secondary container, internal structures (e.g., SIA) and dunnage or shoring shall not exceed 7,300 lbs (3,311 kg).

1.2.2.2 Irradiated Fuel Waste

Irradiated fuel waste includes two types of waste; irradiated LEU fuel waste (Content 2-1) and irradiated CANDU fuel waste (Content 2-2) consisting of:

Type and Form of Material:

1. Radioactive material in the form of LEU waste with or without activated metal structural components (e.g., cladding, liners, baskets, etc.).
2. Irradiated CANDU fuel waste contents and irradiated hardware contents. Irradiated CANDU fuel contents are restricted to natural UO_2 fuel of a typical CANDU fuel bundle design with cladding and bundle structure comprised exclusively of Zircaloy material.
3. CANDU fuel baskets of irradiated hardware materials.

Maximum Quantity per Package:

1. That quantity of any radioactive material not generating spontaneously more than 1,500 watts of radioactive decay heat.
2. Shall not exceed the Fissile Equivalent Mass (FEM) limits from Table 1-3 for the specified criticality configuration limits.
3. IFW contents shall comply with regulatory dose rates, as demonstrated in accordance with Chapter 7, Attachment 7.5-1. Note: Maximum activity limits for key individual gamma-emitting isotopes (e.g., Co-60, Cs-137 and Ba-137m) and neutron-emitting isotopes (e.g., Cf-252 and Cm-244) are provided in Table 1-4.
4. CANDU fuel waste contents shall have a maximum burnup of 5 GWd/MTU, a minimum cooling time of 40 years, and a maximum fuel mass of 1808.8 kg (3,988 lb) UO_2.
5. CANDU fuel baskets of irradiated hardware materials are limited to 2.5 kg (5.5 lb) of Inconel, 200 kg (441 lb) of stainless steel, and unlimited Zircaloy per package.

Loading and Shipping Restrictions:

1. Must be shipped under exclusive use controls.
2. IFW contents shall be in secondary containers (e.g., drums or boxes).

3. IFW contents with a total decay heat exceeding 50 watts shall be inerted with helium gas per Attachment 7.5-2.
4. Free liquids shall not exceed 1% of the CCV cavity volume.
5. CANDU fuel baskets of irradiated hardware materials may not be shipped in the same package as other irradiated CANDU fuel waste contents.
6. Maximum weight of contents, including IFW in a secondary container, internal structures (e.g., SIA, etc.) and dunnage or shoring shall not exceed 7,300 lbs (3,311 kg).

1.2.3 Special Requirements for Plutonium

Plutonium contents in quantities greater than 0.74 TBq (20 Ci) must be in solid form.

1.2.4 Operational Features

The packaging has no special or complex operational features. Chapter 7 describes the operational steps, including use of the packaging's operational features.

Table 1-1 Content Designations

Contents			Content ID
Class	**Type**	**Sub-Type**	
TRU waste	Compliant(1)	---	1-1
	Non-Compliant(1)	Aerosol Cans, Type 1(2)	1-2A
		Aerosol Cans, Type 2(3)	1-2B
		Standard DOT 3E Lecture Bottle	1-2C
Irradiated Fuel Waste	LEU(4)	---	2-1
	CANDU	---	2-2

Notes:

1. Refers to Waste Isolation Pilot Plant (WIPP) Waste Acceptance Criteria (WAC) for TRU waste.
2. Aerosol cans with compressed gas propellant.
3. Aerosol cans with liquified gas propellant or unknown propellant.
4. Low enriched uranium.

Table 1-2 TRU Waste FGE Limits

Config. ID	FGE Criticality Configuration Description				FGE Limit, (g ^{239}Pu)(1)
	Machine Compacted(2)	Weight % Special Reflector(3)	Minimum ^{240}Pu Credit	Chemically or Mechanically Bound	
FGE-1		≤ 1			335
FGE-2a		≤ 1	≥ 5 g		350
FGE-2b		≤ 1	≥ 15 g		370
FGE-2c		≤ 1	≥ 25 g		390
FGE-3		> 1			121
FGE-4		> 1		✓	320
FGE-5	✓	≤ 1			245

Note:

(1) FGE equivalents determined as described in Section 6.3.4. FGE conversion based on a ratio of subcritical mass limits in ANSI/ANS-8.1 [1-7], Section 5.2 of 0.7 kg (1.5 lb) for ^{235}U and 0.45 kg (1.0 lb) for ^{239}Pu (See Table 7-1).

(2) For uncompacted or manually compacted TRU waste, materials with hydrogen density up to that of water (0.1117 g/cm^3) are unlimited, but materials with hydrogen density greater than water are limited to the hydrogen density of polyethylene (0.1336 g/cm^3) and may not exceed 15% of the total contents by volume. For machine compacted contents, hydrogenous materials in the contents are limited to the hydrogen density of polyethylene (0.1336 g/cm^3) in an unlimited quantity.

(3) Special reflector materials are defined as beryllium, beryllium oxide, carbon (graphite), heavy water, magnesium oxide, and depleted uranium. The weight% of the special reflector materials is calculated as the mass of all special reflector materials present divided by the total mass of all waste material contents inside the secondary container. For FGE-3, these materials are unlimited.

Table 1-3 IFW FEM Limits

Config. ID[1]	LEU Waste Criticality Configuration Description			Uranium Mass Limit (lb)
	Weight % Special Reflector[2]	Enrichment Limit (wt% U-235)	Particle Size Restriction (cm)	
FEM-1	≤ 1	≤ 0.96 wt%	≤ 0.1 and/or ≥ 8.0	5,000
FEM-2	≤ 1	≤ 0.80 wt%	N/A	

Note:

(1) IFW contents must be non-machine compacted. Materials with hydrogen density up to that of water (0.1117 g/cm^3) are unlimited, but materials with hydrogen density greater than water are limited to the hydrogen density of polyethylene (0.1336 g/cm^3) and may not exceed 15% of the total contents by volume.

(2) Special reflector materials are defined as beryllium, beryllium oxide, carbon (graphite), heavy water, magnesium oxide, and depleted uranium. The weight% of the special reflector materials is calculated as the mass of all special reflector materials present divided by the total mass of all waste material contents inside the secondary container.

Table 1-4 TRU Waste and IFW Activity Limits for Key Isotopes

Isotope	Activity Limits[1] for Package Configurations (Ci)			
	Bare[2]	[redacted] SIA[3]	[redacted] SIA[4]	[redacted] SIA[5]
Open Transport – Nonexclusive Use (TRU Waste only)				
Co-60	1.880E-01	4.708E-01	1.484E+00	6.126E+00
Cs-137	3.452E+04	1.306E+05	6.549E+05	4.390E+06
Ba-137m	6.781E+00	2.434E+01	1.210E+02	8.567E+02
Cf-252	2.918E-04	3.143E-04	3.411E-04	3.888E-04
Cm-244	9.186E+00	9.892E+00	1.073E+01	1.222E+01
Open Transport – Exclusive Use				
Co-60	4.635E-01	8.820E-01	3.412E+00	1.073E+01
Cs-137	7.951E+04	1.432E+05	1.268E+06	4.655E+06
Ba-137m	1.572E+01	2.855E+01	2.525E+02	8.567E+02
Cf-252	7.595E-04	7.930E-04	8.590E-04	9.962E-04
Cm-244	2.393E+01	2.497E+01	2.703E+01	3.132E+01
Closed Transport				
Co-60	5.804E-01	1.327E+00	4.426E+00	1.899E+01
Cs-137	1.129E+05	3.970E+05	1.268E+06	1.405E+07
Ba-137m	2.225E+01	7.266E+01	2.562E+02	2.837E+03
Cf-252	8.986E-04	9.867E-04	1.060E-03	1.195E-03
Cm-244	2.831E+01	3.105E+01	3.334E+01	3.761E+01

Notes:

(1) Activity limits are provided for the entire content in a package. The corresponding maximum dose rates for the isotopes are shown for the bare configuration in Table 7.5-1 (exclusive use) and Table 7.5-2 (nonexclusive use), for the [redacted] SIA configuration in Table 7.5-3 (exclusive use) and Table 7.5-4 (nonexclusive use), for the [redacted] SIA configuration in Table 7.5-5 (exclusive use) and Table 7.5-6 (nonexclusive use), and for the [redacted] SIA configuration in Table 7.5-7 (exclusive use) and Table 7.5-8 (nonexclusive use). Compliance with external dose rate limits shall be demonstrated with the isotope inventory of the individual package contents using the dose rate per curie values listed in these tables, as outlined in Attachment 7.5.1.

(2) Package configuration without an SIA inside the CCV cavity.

- [redacted]

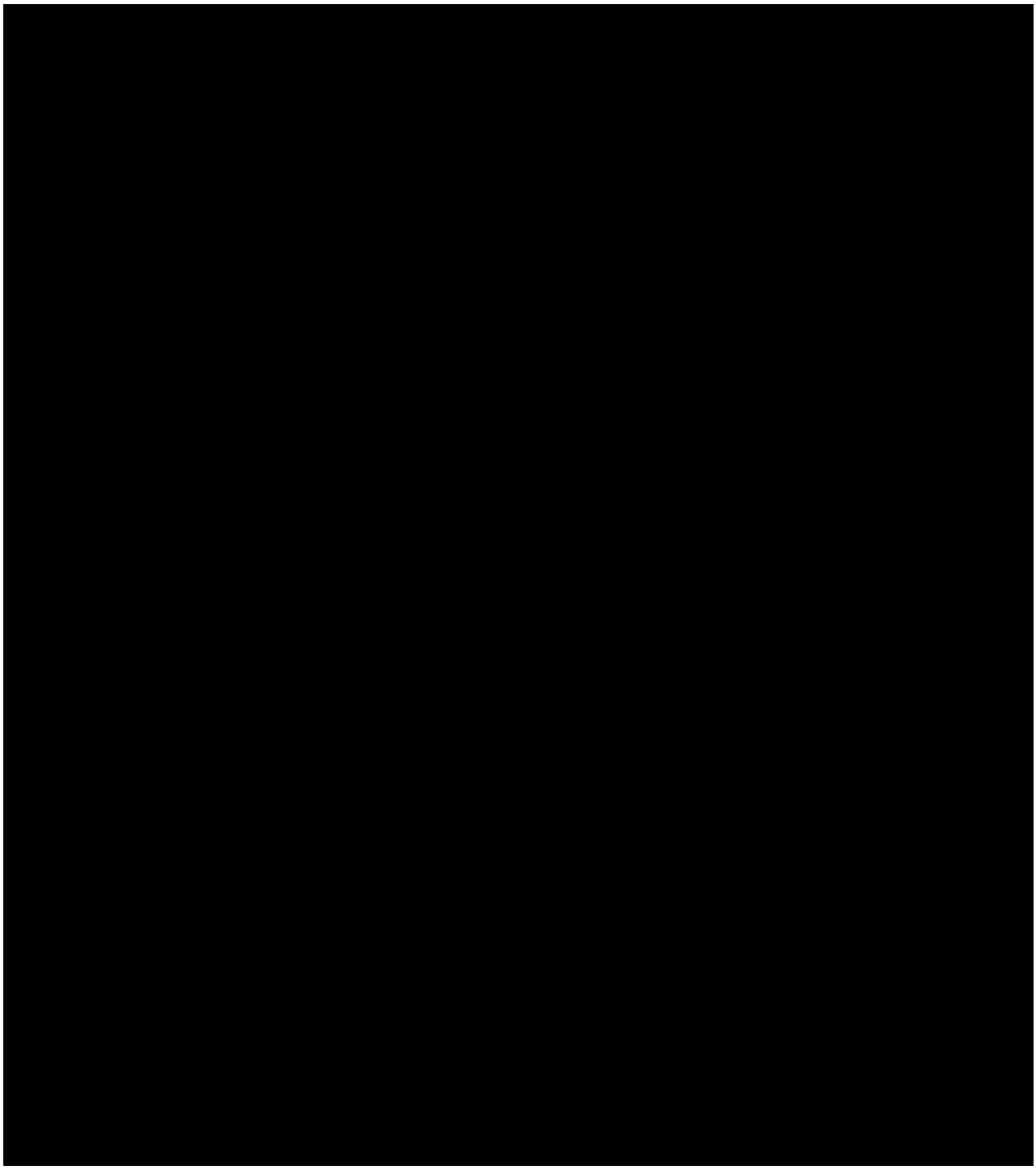


Figure 1-2 CCV Packaging Components

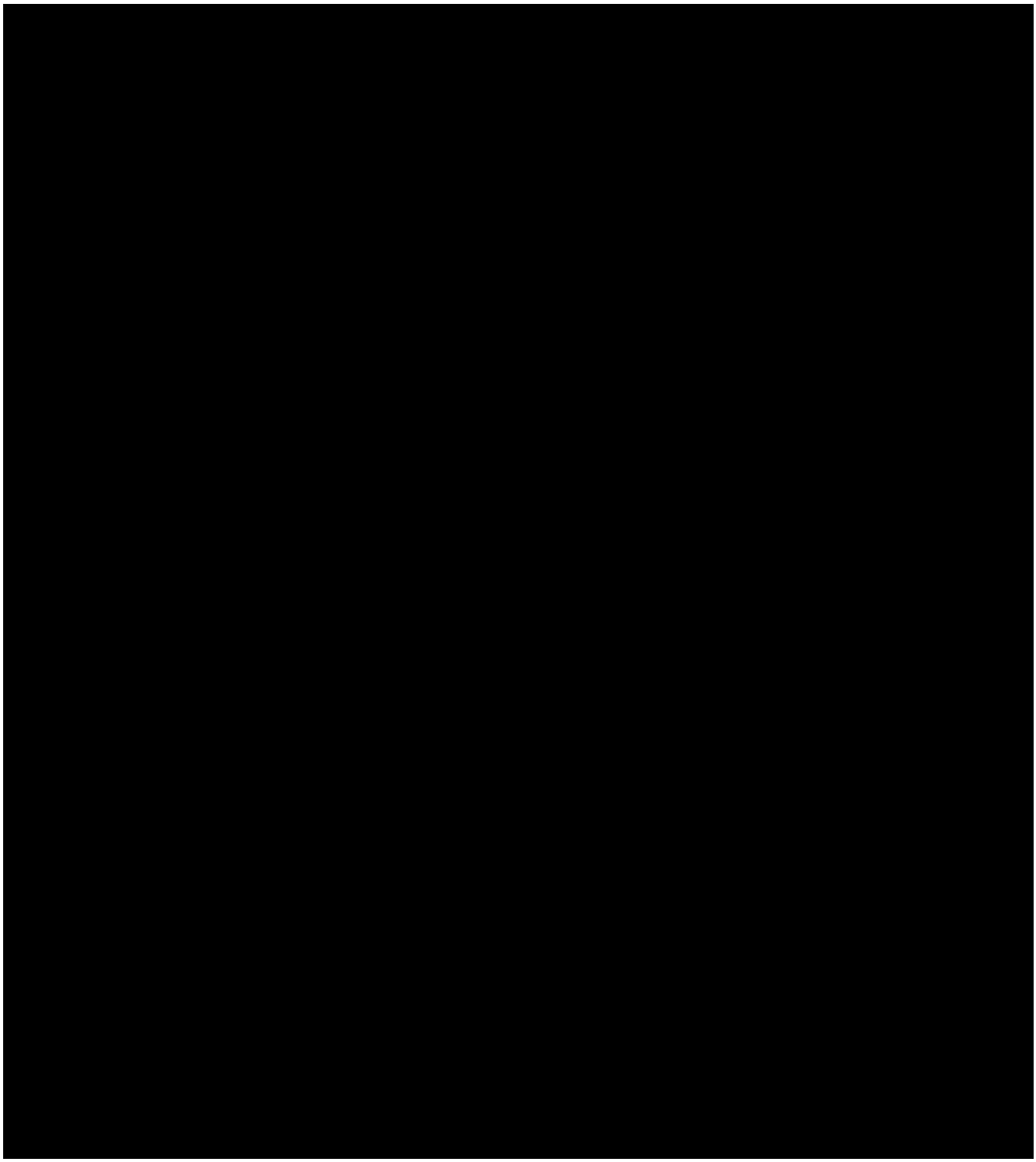


Figure 1-3 OSV Packaging Components

Figure 1-4 Impact Limiter Packaging Components

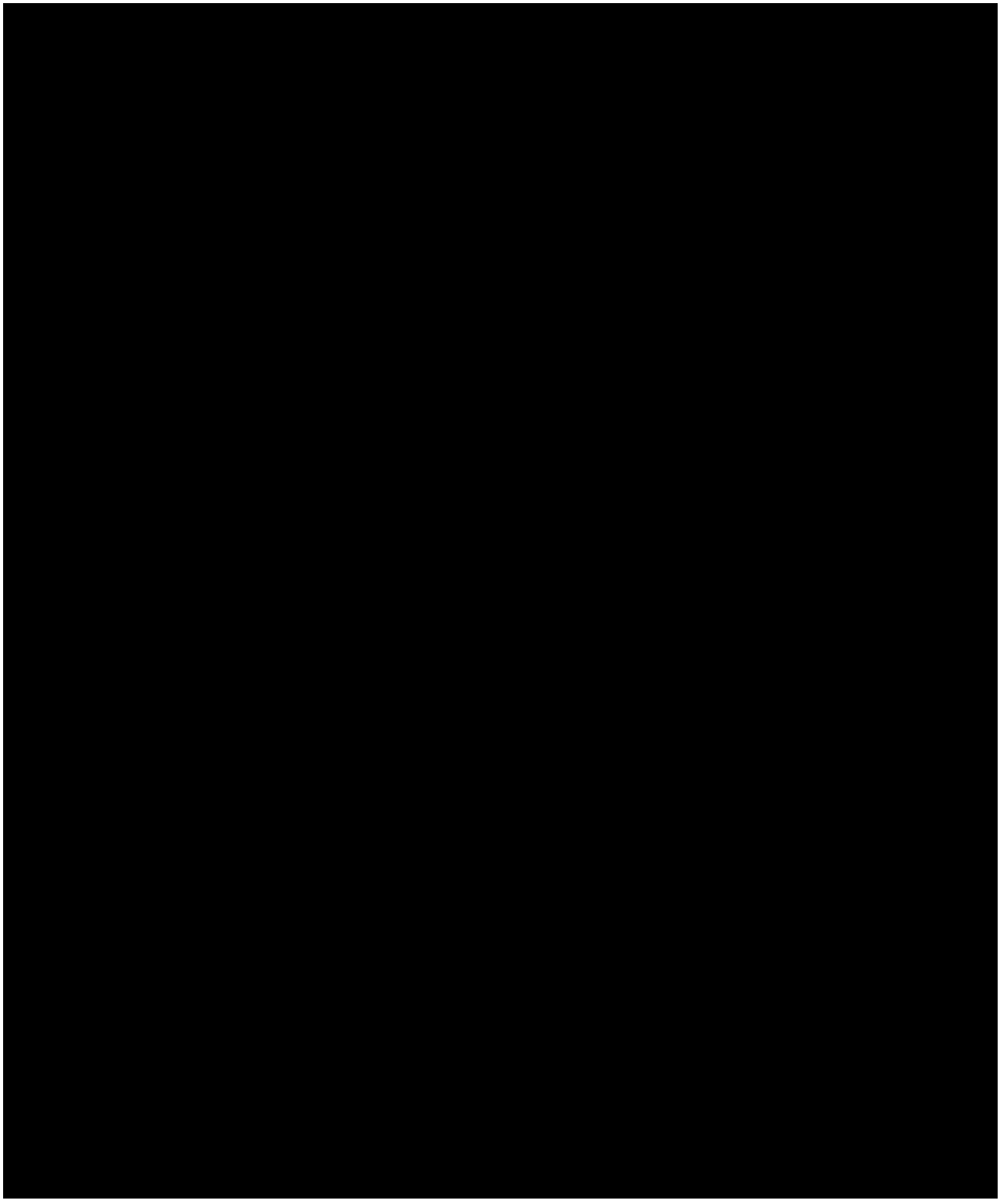


Figure 1-5 Packaging Containment System

THIS PAGE INTENTIONALLY LEFT BLANK

1.3 Appendix

1.3.1 References

[1-1] ANSI N14.5-2014, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*, American National Standards Institute, Inc., June 19, 2014.

[1-2] Regulatory Guide 7.6, *Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels*, Revision 1, March 1978.

[1-3] Fischer, L. E., and Lai, W., *Fabrication Criteria for Shipping Containers*, NUREG/CR-3854, UCRL-53544, U.S. Nuclear Regulatory Commission, March 1985.

[1-4] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, *Class 1 Components*, 2010 Edition with 2011 Addenda.

[1-5] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NF, *Supports*, 2010 Edition with 2011 Addenda.

[1-6] NUREG/CR-5502, *Engineering Drawings for 10 CFR Part 71 Package Approvals*, U.S. Nuclear Regulatory Commission, May 1998.

[1-7] ANSI/ANS-8.1-2014, "Nuclear Criticality Safety In Operations With Fissionable Materials Outside Reactors".

1.3.2 Glossary of Terms and Acronyms

ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
B&PVC	Boiler and Pressure Vessel Code
CSI	Criticality Safety Index
DOT	United States Depertment of Transportation
FEM	Fissile Equivalent Mass (^{235}U)
FGE	Fissile Gram Equivalent (^{239}Pu)
HAC	Hypothetical Accident Conditions
IAEA	International Atomic Energy Agency
ICV	Inner Containment Vessel
ILS	Impact Limiter System
LEU	Low-Enriched Uranium
MNOP	Maximum Normal Operating Pressure
NCT	Normal Conditions of Transport
NRC	United States Nuclear Regulatory Commission
OSV	Outer Shield Vessel
Package	The packaging with its radioactive contents (payload), as presented for transportation. Within this report, the package is denoted as the OPTIMUS®-H package.
Packaging	The assembly of components necessary to ensure compliance with packaging requirements. Within this report, the Packaging is denoted as the OPTIMUS®-H packaging, or simply as the packaging.
pcf	pounds per cubic foot
SAR	Safety Analysis Report
SIA	Shield Insert Assembly
TRU	Transuranic Waste

1.3.3 Packaging General Arrangement Drawings

The following drawings show the general arrangement and design features of the OPTIMUS®-H packaging in accordance with NUREG/CR-5502 [1-6]. The drawings refer to material specifications, welding requirements, inspection and test requirements, and dimensions as necessary to support the safety analyses.

Drawing No.	Title	Rev.
70000.14-501	Packaging Assembly – OPTIMUS-H	4
70000.14-510	CCV Assembly – OPTIMUS	6
70000.14-511	CCV Body Weldment – OPTIMUS	9
70000.14-512	CCV Lid – OPTIMUS	8
70000.14-513	Port Cover – OPTIMUS	3
70000.14-520	OSV Assembly – OPTIMUS-H	5
70000.14-521	OSV Body – OPTIMUS-H	10
70000.14-522	OSV Lid – OPTIMUS-H	9
70000.14-530	Impact Limiter Assembly - OPTIMUS-H	7
70000.14-550	[redacted] Shield Insert Assembly (SIA) - OPTIMUS	4
70000.14-551	[redacted] Shield Insert Assembly (SIA) - OPTIMUS	5
70000.14-552	[redacted] Shield Insert Assembly (SIA) - OPTIMUS	2

THIS PAGE INTENTIONALLY LEFT BLANK

Chapter 2
Structural Evaluation

Table of Contents

2 STRUCTURAL EVALUATION 2-1
2.1 Description of Structural Design 2.1-1
2.1.1 Discussion 2.1-1
2.1.2 Design Criteria 2.1-4
2.1.3 Weights and Centers of Gravity 2.1-13
2.1.4 Identification of Codes and Standards for Packaging 2.1-13
2.2 Materials 2.2-1
2.2.1 Material Properties and Specifications 2.2-1
2.2.2 Chemical, Galvanic or Other Reactions 2.2-2
2.2.3 Effects of Radiation on Materials 2.2-5
2.3 Fabrication and Examination 2.3-1
2.3.1 Fabrication 2.3-1
2.3.2 Examination 2.3-3
2.4 General Requirements for All Packages 2.4-1
2.4.1 Minimum Package Size 2.4-1
2.4.2 Tamper-Indicating Feature 2.4-1
2.4.3 Positive Closure 2.4-1
2.5 Lifting and Tie-Down Standards for All Packages 2.5-1
2.5.1 Lifting Devices 2.5-1
2.5.2 Tie-Down Devices 2.5-3
2.6 Normal Conditions of Transport 2.6-1
2.6.1 Heat 2.6-1
2.6.2 Cold 2.6-8
2.6.3 Reduced External Pressure 2.6-9
2.6.4 Increased External Pressure 2.6-12
2.6.5 Vibration 2.6-12
2.6.6 Water Spray 2.6-13
2.6.7 Free Drop 2.6-13
2.6.8 Corner Drop 2.6-39
2.6.9 Compression 2.6-39
2.6.10 Penetration 2.6-39
2.7 Hypothetical Accident Conditions 2.7-1
2.7.1 Free Drop 2.7-1
2.7.2 Crush 2.7-33
2.7.3 Puncture 2.7-33
2.7.4 Thermal 2.7-39
2.7.5 Immersion – Fissile Material 2.7-43
2.7.6 Immersion – All Packages 2.7-43

2.7.7 Deep-Water Immersion Test (for Type B Packages Containing more than 10^5 A_2) 2.7-43
2.7.8 Summary of Damage 2.7-47
2.8 Accident Conditions for Air Transport of Plutonium 2.8-1
2.9 Accident Conditions for Fissile Material Packages for Air Transport 2.9-1
2.10 Special Form 2.10-1
2.11 Fuel Rods 2.11-1
2.12 Appendix 2.12-1
2.12.1 References 2.12-1
2.12.2 Computer Code Descriptions 2.12-4
2.12.3 [redacted] 2.12-5
2.12.4 Development of Equivalent Static Loads 2.12-7
2.12.5 Closure Bolt Evaluation 2.12-10

List of Figures

Figure 2.1-1 CCV and OSV Stress Evaluation Locations 2.1-21
Figure 2.1-2 Package Mass Properties Schematic 2.1-22
Figure 2.2-1 [redacted] Upper and Lower-Bound Dynamic Stress-Strain Curves 2.2-11
Figure 2.2-2 [redacted] Upper and Lower-Bound Dynamic Stress-Strain Curves 2.2-11
Figure 2.5-1 Package Tie-Down Configuration 2.5-6
Figure 2.5-2 Alternate Package Tie-Down Configuration (Using OSV Trunnions) 2.5-7
Figure 2.6-1 ½-Symmetry FEA Stress Analysis Model 2.6-6
Figure 2.6-2 Bounding NCT Heat Temperature Distribution 2.6-7
Figure 2.6-3 NCT 2-Foot (0.6 m) Free Drop Impact Orientations 2.6-31
Figure 2.6-4 Drop Analysis [redacted] – Isometric View 2.6-32
Figure 2.6-5 Drop Analysis [redacted] – Impact Limiter Detail 2.6-33
Figure 2.6-6 Drop Analysis [redacted] – OSV Closure Detail 2.6-33
Figure 2.6-7 Drop Analysis [redacted] – CCV Closure Detail 2.6-34
Figure 2.6-8 NCT [redacted] y Top End Drop (Case NE2) Impact Limiter Deformation 2.6-35
Figure 2.6-9 NCT [redacted] Top End Drop (Case NE1) [redacted] Acceleration Time-History 2.6-35
Figure 2.6-10 NCT [redacted] Top Corner Drop (Case NC1) Impact Limiter Deformation 2.6-36
Figure 2.6-11 NCT [redacted] Top Corner Drop (Case NC1) Rigid-Body Acceleration Time-History 2.6-36
Figure 2.6-12 NCT [redacted] Side Drop (Case NS2) Impact Limiter Deformation 2.6-37
Figure 2.6-13 NCT [redacted] Side Drop (Case NS1) [redacted] Acceleration Time-History 2.6-37
Figure 2.6-14 [redacted] 2.6-38
Figure 2.7-1 HAC Free Drop Impact Orientations 2.7-5
Figure 2.7-2 HAC [redacted] Top End Drop (Case HE2) Impact Limiter Deformation 2.7-12
Figure 2.7-3 HAC [redacted] Top End Drop (Case HE1) [redacted] Acceleration Time-History 2.7-13
Figure 2.7-4 HAC [redacted] Top End Drop (Case HE3) [redacted] Acceleration Time-History 2.7-13
Figure 2.7-5 HAC [redacted] Side Drop (Case HS2) Impact Limiter Deformation 2.7-18
Figure 2.7-6 HAC [redacted] t Side Drop (Case HS1) [redacted] Acceleration Time-History 2.7-19
Figure 2.7-7 HAC [redacted] Side Drop (Case HS3) [redacted] Acceleration Time-History 2.7-19
Figure 2.7-8 HAC [redacted] Top Corner Drop (Case HC2) Impact Limiter Deformation 2.7-25
Figure 2.7-9 HAC [redacted] Top Corner Drop (Case HC1) [redacted] Acceleration Time-History 2.7-26

Figure 2.7-10 HAC [redacted] Top Corner Drop (Case HC3) [redacted] Acceleration Time-History 2.7-26
Figure 2.7-11 HAC [redacted] 5° Oblique Drop (Case HO1) Impact Limiter Deformations..... 2.7-30
Figure 2.7-12 HAC [redacted] 5° Oblique Drop (Case HO1) [redacted] Acceleration Time-History 2.7-30
Figure 2.7-13 HAC [redacted] 10° Oblique Drop (Case HO2) Impact Limiter Deformation 2.7-31
Figure 2.7-14 HAC [redacted] 10° Oblique Drop (Case HO2) [redacted] Acceleration Time-History 2.7-31
Figure 2.7-15 HAC Puncture Drop Top End Impact Orientations 2.7-36
Figure 2.7-16 Cumulative Impact Limiter Deformation - HAC Top End Drop and HAC Puncture Center Impact 2.7-37
Figure 2.7-17 Impact Limiter Deformation - HAC Top End Off-Center Puncture Impact 2.7-38
Figure 2.12-1 Benchmark Comparison of HAC Side Drop Analysis and Test Results 2.12-6
Figure 2.12-2 [redacted] 2.12-9

List of Tables

Table 2.1-1 Load Combinations for Normal Conditions of Transport 2.1-15
Table 2.1-2 Load Combinations for Hypothetical Accident Conditions 2.1-16
Table 2.1-3 Containment System Allowable Stress Design Criteria 2.1-17
Table 2.1-4 Non-Containment Component Allowable Stress Design Criteria 2.1-18
Table 2.1-5 CCV Shell Buckling Geometric Parameters 2.1-19
Table 2.1-6 CCV Shell Buckling Reduction Factors and Theoretical Buckling Stresses 2.1-19
Table 2.1-7 CCV Shell Allowable Buckling Stresses 2.1-20
Table 2.1-8 Package Weight and Center of Gravity Summary 2.1-20
Table 2.2-1 Packaging Structural Material Specifications 2.2-6
Table 2.2-2 [redacted] 2.2-7
Table 2.2-3 [redacted] 2.2-7
Table 2.2-4 [redacted] 2.2-8
Table 2.2-5 [redacted] 2.2-8
Table 2.2-6 [redacted] 2.2-9
Table 2.2-7 [redacted] 2.2-9
Table 2.2-8 [redacted] 2.2-10
Table 2.2-9 [redacted] 2.2-10
Table 2.6-1 Reduced External Pressure Stress Summary 2.6-11
Table 2.6-2 Summary of NCT Free Drop Cases Evaluated 2.6-27
Table 2.6-3 NCT Free Drop Impact Analysis Results 2.6-27
Table 2.6-4 NCT Top End Drop Stress Summary 2.6-28
Table 2.6-5 NCT Side Drop Stress Summary 2.6-29
Table 2.6-6 CCV Shell NCT Free Drop Buckling Evaluation Stress Summary 2.6-30
Table 2.6-7 CCV Shell Buckling Evaluation Results for NCT Free Drop 2.6-30
Table 2.7-1 Summary of HAC Free Drop Cases Evaluated 2.7-4
Table 2.7-2 HAC End Drop Impact Limiter Analysis Results 2.7-10
Table 2.7-3 HAC Top End Drop Stress Summary 2.7-10
Table 2.7-4 CCV Shell HAC End Drop Buckling Evaluation Stress Summary 2.7-11
Table 2.7-5 CCV Shell Buckling Evaluation Results for HAC Bottom End Drop 2.7-11
Table 2.7-6 HAC Side Drop Impact Limiter Analysis Results 2.7-17
Table 2.7-7 HAC Side Drop Stress Summary 2.7-17
Table 2.7-8 HAC Corner Drop Impact Limiter Analysis Results 2.7-24
Table 2.7-9 HAC Oblique Drop Impact Limiter Analysis Results 2.7-29
Table 2.7-10 HAC Pressure Stress Summary 2.7-42
Table 2.7-11 Deep Water Immersion Test Stress Summary 2.7-45
Table 2.7-12 CCV Shell Buckling Summary for Deep Water Immersion Test 2.7-46
Table 2.12-1 [redacted] 2.12-6
Table 2.12-2 Closure Bolt Geometry and Material Properties 2.12-15

Table 2.12-3 Summary of Bolt Temperature Load Parameters 2.12-16
Table 2.12-4 Closure Bolt Loads 2.12-17
Table 2.12-5 Closure Bolt Combined Loads 2.12-18
Table 2.12-6 Closure Bolt NCT Stresses and Interaction Ratios 2.12-19
Table 2.12-7 Closure Bolt HAC Stresses and Interaction Ratios 2.12-20

2 STRUCTURAL EVALUATION

The structural evaluation of the OPTIMUS®-H packaging demonstrates compliance with the applicable performance requirements of 10 CFR 71. Compliance with the applicable general requirements of 10 CFR 71.43(a), (b), and (c) is demonstrated in Section 2.4. Compliance with the lifting and tie-down standards of 10 CFR 71.45(a) and (b) is demonstrated in Section 2.5. The structural evaluation for NCT tests (10 CFR 71.71) and HAC tests (10 CFR 71.73) presented in Sections 2.6 and 2.7, respectively, demonstrates the packaging satisfies the applicable structural design criteria, as described in Section 2.1.2.

The results of the structural evaluation demonstrate that the packaging will experience no loss or dispersal of radioactive contents, no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging under NCT tests. Therefore, the packaging satisfies the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a)(1). The structural evaluation also shows the cumulative packaging damage resulting from the HAC test sequence does not result in escape of other radioactive material exceeding a total amount of A_2 in one week, nor does it result in an external radiation dose rate that exceeds 10 mSv/h (1000 mrem/h) at 1 m from the external surface of the packaging. Thus, the packaging satisfies the requirements of 10 CFR 71.51(a)(2).

This page intentionally left blank.

2.1 Description of Structural Design

2.1.1 Discussion

The principal structural members important to the safe operation of the packaging, shown on General Arrangement Drawing 70000.14-501, are the cask containment vessel (CCV), outer shield vessel (OSV), and impact limiter system (ILS). The CCV is the central component of the packaging that provides containment of the radioactive contents. The OSV provides shielding, structural, thermal protection of the CCV. The ILS limits the impact loads imparted to the OSV and CCV under NCT and HAC free drop tests and insulates the top and bottom ends of the package from the effects of the HAC thermal test. An optional shield insert assembly (SIA) may be used inside the CCV to provide additional shielding for high activity contents. The structural design of these assemblies is described in the following sections.

2.1.1.1 Cask Containment Vessel

The primary structural components of the Cask Containment Vessel (CCV) assembly, shown on General Arrangement Drawing 70000.14-510, are the CCV body weldment, the CCV lid and its [redacted] closure bolts, and the CCV port cover and its [redacted] closure bolts. The CCV lid is placed in the top end of the CCV body and captured by the closure lid bolts. The internal cylindrical cavity volume, formed by the CCV body weldment and CCV lid, houses the payload.

The CCV body weldment, shown on General Arrangement Drawing 70000.14-511, is constructed entirely from austenitic stainless steel and is formed from three pieces that are connected by complete joint penetration welds: a cylindrical shell, a bolting flange, and a bottom plate. The bolting flange includes [redacted] threaded holes for the CCV closure bolts.

The CCV lid, shown on General Arrangement Drawing 70000.14-512, is a stepped circular plate that includes [redacted] holes for captured bolts, dovetail grooves for the lid's containment and test O-rings, two (2) lid O-ring test ports, a vent/fill port, and threaded holes used to lift the CCV lid or the loaded CCV assembly. [redacted] The vent/fill port, which includes a quick-connect fitting that is not relied upon for containment, is used to evacuate the CCV cavity and contents of air and backfill with helium gas. The vent/fill port is closed and sealed by the CCV port cover described below. The leak-test ports in the CCV lid are used to perform fabrication acceptance, maintenance, and periodic leakage rate tests of the CCV lid containment seal, and the

pre-shipment leakage rate test prior to each shipment. A sealed plug is installed in each test port prior to shipment to prevent debris or water from entering the leak-test port cavity.

The CCV port cover, shown on General Arrangement Drawing 70000.14-513, is a circular plate that includes [redacted] holes for the closure bolts, dovetail grooves for the port cover containment and test O-rings, and [redacted] port cover O-ring test ports. [redacted] The leak-test ports in the CCV port cover are used to perform fabrication acceptance, maintenance, and periodic leakage rate tests of the CCV lid containment seal, and the pre-shipment leakage rate test prior to each shipment. A sealed plug is installed in each port cover test port prior to shipment to prevent debris or water from entering the test port cavity.

2.1.1.2 Outer Shield Vessel

The primary structural components of the Outer Shield Vessel (OSV) assembly, shown on General Arrangement Drawing 70000.14-520, are the OSV body, the OSV lid and its [redacted] closure bolts. The OSV lid is placed in the top end of the OSV body and captured by the OSV closure lid bolts. The internal cylindrical cavity of the OSV assembly, formed by the OSV body assembly and OSV closure lid, houses the CCV.

The OSV body, shown on General Arrangement Drawing 70000.14-521, is cast from ductile iron as a monolithic unit, including the four (4) tiedown lugs, two (2) lifting trunnions, and [redacted] mpact limiter attachment brackets located on the exterior of the side wall. The four (4) tiedown lugs located on the OSV body sidewall are used to tiedown the package during transport but may also be used to lift the loaded package. The two (2) integral lifting trunnions cast into the side wall of the OSV body can be used to lift the loaded package and may also be used to tiedown the package during transport. The impact limiter attachment brackets are located near the top and bottom ends of the packaging side wall. [redacted] impact limiter attachment brackets are used to secure each impact limiter assembly to the OSV assembly.

The OSV body's bolting flange includes [redacted] steel anchors with threaded holes for the CCV closure bolts. [redacted]

The OSV body also includes a drain port extending through the OSV body sidewall at the bottom end of the cavity. The drain port, filled with a threaded steel plug during transport, does not have a safety function during transportation. The drain port plug provides shielding to reduce radiation streaming through the drain port.

The OSV lid, shown on General Arrangement Drawing 70000.14-522, is a stepped circular plate that includes [redacted] holes for the OSV lid bolts and threaded holes used to lift the OSV lid. The OSV lid does not include any ports or penetrations. [redacted]

2.1.1.3 Impact Limiter System

The Impact Limiter System (ILS) consists of impact limiter assemblies secured to the top and bottom ends of the OSV that limit the impact loading on the package from the NCT free drop, HAC free drop, and HAC puncture drop tests and to provide thermal protection during the HAC thermal (fire) test. The impact limiters, shown on General Arrangement Drawing 70000.14-530, are constructed of fully welded stainless steel shells filled with closed-cell rigid polyurethane foam. The foam deforms and provides energy absorption during impact. [redacted] attachment lugs are provided to connect each impact limiter to the OSV body. Each impact limiter attachment consists of an alloy swing bolt secured to a steel lug attached to the inner shell of the impact limiter. Each impact limiter swing bolt attaches to an integral bracket to the OSV body.

2.1.1.4 Shield Inserts

The [redacted] shield insert assembly (SIA) shown on General Arrangement Drawings 70000.14-550, -551 and -552, respectively, are used inside the CCV for radioactive contents with increased activities that require additional shielding to satisfy regulatory dose rate limits. All [redacted] SIA designs include a body weldment and the [redacted] lid weldments. The SIA lid is placed in the top end of the SIA body and captured by the CCV lid when it is installed. The internal cylindrical cavity volume of the SIA houses the payload. Additional discussion of the fabrication and examination requirements for the SIAs is provided in Section 2.3.

Although no structural credit is taken for the SIA in the structural evaluation of the other packaging components, the SIA is designed to withstand the most severe regulatory tests (e.g., free drop) without structural failure, such that shielding integrity is maintained for those conditions in which the SIAs are credited in the shielding evaluation.

2.1.2 Design Criteria

The design criteria used for the structural design of the packaging is selected in accordance with the codes and standards identified in Section 2.1.4. Structural analyses of the packaging are performed for the applicable NCT tests (i.e., 10 CFR 71.71) and HAC tests (i.e., 10 CFR 71.73). The combination of initial conditions used for the structural evaluation of each NCT and HAC test are discussed in Section 2.1.2.1. The stresses in the packaging structural components are calculated for the NCT and HAC load combinations and compared to the allowable stress design criteria described in Section 2.1.2.2. Other structural failure modes, such as brittle buckling, fatigue, and brittle fracture, are evaluated using the design criteria discussed in Sections 2.1.2.3 through 2.1.2.5.

2.1.2.1 Load Combinations

The load combinations used for the structural evaluation of the packaging are developed in accordance with Regulatory Guide 7.8 [2.3]. The load combinations are based on Table 2.1-1 of Regulatory Guide 7.8, with additional load combinations for intermediate initial conditions that could possibly create a more limiting case for the packaging design. The NCT and HAC load combinations are summarized in Table 2.1-1 and Table 2.1-2, respectively.

2.1.2.2 Allowable Stresses

In accordance with Regulatory Guide 7.6 [2.4], the pressure-retaining components of the packaging containment system, which consist of the CCV body weldment, closure lid, and closure bolts, are designed in accordance with the requirements of Section III, Subsection NB of the ASME Code [2.5]. Level A and Level D Service Limits are used for NCT and HAC, respectively. The containment system stress intensity limits for NCT are developed in accordance with Figures NB-3221-1 and NB-3222-1 and summarized in Table 2.1-3. Per NB-3224, the containment system stress intensity limits for HAC are developed in accordance with Appendix F of the ASME Code [2.6], as summarized in Table 2.1-3.

All packaging structural components that are not relied upon for containment, except for the impact limiter assemblies, are designed in accordance with the allowable stress design criteria for Class 2 plate- and shell-type supports from Subsection NF of the ASME Code [2.7]. The NCT and HAC allowable stress design criteria for the packaging non-containment components are summarized in Table 2.1-4.

Subsections NF and NB of the ASME Code impose stress limitations on primary membrane, local membrane, membrane (primary or local) plus bending, and primary plus secondary stress intensities. To demonstrate conformance to the ASME Code limits, it is necessary to determine

the required code stress intensities at the critical cross-sections of the packaging. Since the critical cross-section locations are load-condition-dependent, several "stress evaluation sections" are established to ensure that all critical locations have been evaluated for every load condition. The stress evaluation sections selected for the packaging containment system and non-containment components are illustrated in Figure 2.1-1. Multiple sections are selected in the high stress regions near the ends of the shells. For evaluation of conditions producing a stress distribution in the packaging that is not axisymmetric, section stress evaluations are performed at multiple circumferential locations to assure that the maximum stresses are captured. For the CCV shell buckling evaluation, membrane stress components at the mid-length of the CCV shell (section C7) are used.

The section stresses at each stress evaluation location are obtained using the [redacted] The stress linearization provides membrane, bending, membrane plus bending, peak, and total stress intensities at each section. These stresses are classified in accordance with the ASME Code for comparison to the applicable allowable stress design criteria as follows:

Membrane Stress Intensity

The membrane stress intensities are classified as primary membrane (P_m) or local membrane (P_l) based upon the location in the structure and the nature of the stress. Membrane stresses occurring at a structural discontinuity (e.g., at the transition inner shell thickness transitions and at the shell-to-flange transitions) are classified as local membrane, provided that the distance over which the membrane stress intensity exceeds the P_m limit does not exceed $1.0(Rt)^{1/2}$, where R is the minimum mid-surface radius of curvature and t is the minimum thickness in the region considered. Membrane stresses at all other sections are classified as primary.

Membrane Plus Bending Stress Intensity

The membrane plus bending stress intensities at each section are classified as either primary (P_m+P_b) or secondary (P_m+P_b+Q) based upon the location in the structure. Bending stresses at gross structural discontinuities, such as flange-to-shell junctions and junctions between shells of different diameters or thickness, are classified as secondary. Membrane plus bending stress intensities at all other stress sections are classified as primary.

Total Stress Intensity

Total stress intensities include primary plus secondary plus peak stresses. In accordance with the ASME Code, these stresses are objectionable only as a possible source of a fatigue crack or a brittle fracture. As shown in Section 2.1.2.4, evaluation of cyclic loading is not required for the packaging components other than bolts.

Using the critical sections from each load case, minimum design margins are calculated and reported for all bounding load combinations. The design margin (D.M.) is defined as follows:

$$\text{D.M.} = \left(\frac{\text{Allowable Value}}{\text{Calculated Value}} \right) - 1 ;$$

where the allowable and calculated values are in consistent units.

The impact limiter shells are designed to deform plastically and absorb the kinetic energy when subjected to the NCT free drop, HAC free drop, and HAC puncture drop load conditions. Therefore, strain-based design criteria are used for the impact limiter. The maximum crush depth of the polyurethane foam in the impact limiter is generally limited to 70% of the nominal foam section thickness. In cases of highly localized foam crush, e.g., that due to the HAC hot corner drop impact, the maximum foam crush depth may not exceed 80% of the nominal foam section thickness

2.1.2.3 Buckling

2.1.2.3.1 CCV Shell

The CCV shell is evaluated for buckling in accordance with the requirements of ASME Code Case N-284-1 [2.8]. The geometric parameters of the CCV shell used for the buckling evaluation are summarized in Table 2.1-5. Capacity reduction factors are calculated in accordance with Section -1511 of ASME Code Case N-284-1 to account for possible reductions in the capacity of the CCV shell due to imperfections and nonlinearity in geometry and boundary conditions. Plasticity reduction factors, which account for nonlinear material properties when the product of the classical buckling stresses and capacity reduction factors exceed the proportional limit, are calculated in accordance with Section -1610 of ASME Code Case N-284-1. The theoretical buckling stresses of the CCV shell under uniform stress fields are calculated in accordance with Section -1712.1.1 of ASME Code Case N-284-1. CCV shell lower-bound material properties at an upper-bound temperature of 350°F (177°C) are conservatively used to determine the buckling factors and theoretical buckling stresses. The capacity reduction factors, plasticity reduction factors, and theoretical buckling stresses for the packaging inner and outer shells are summarized in Table 2.1-6.

The allowable elastic and inelastic buckling stresses for NCT and HAC are calculated in accordance with the formulas given in Section -1713.1.1 and Section -1713.2.1 of ASME Code Case N-284-1. The allowable buckling stresses include factors of safety of 2.0 for NCT and 1.34 for HAC in accordance with Section -1400 of ASME Code Case N-284-1. Table 2.1-7 provides a summary of the CCV shell elastic and inelastic buckling stresses for NCT and HAC. Buckling

interaction ratios are calculated for the CCV shell for all NCT and HAC tests that load the shell in compression. The interaction ratios for elastic buckling and inelastic buckling are calculated using the highest values of compressive stress and shear stress in accordance with the formulas given in Section -1713.1.1 and Section -1713.2.1 of ASME Code Case N-284-1.

2.1.2.3.2 Shield Inserts

The shield inset base structure is evaluated for buckling under NCT bottom end free drop loading in accordance with the requirements of ASME Subsection NF [2.7]. Per Table NF-3221.2-1 of Subsection NF of the ASME Code [1], for normal conditions (i.e., Service Level A) the stress is limited to ½ of the critical buckling stress. Stated differently, the minimum factor of safety required against buckling is 2.

2.1.2.4 Fatigue

2.1.2.4.1 Structural Components Other Than Bolts

Analysis of the packaging structural components for cyclic service is not required because the conditions stipulated in NB-3222.4(d)(1) through (6) are met. The analysis is conservatively based on the assumption that the packaging will be used for 20 years of service and be used for one shipment per week, for a total of 1,040 shipments. This analysis is summarized as follows:

1. The number of atmospheric to operating pressure cycles, which is equal to the number of shipments (1,040 cycles), is less than 2,750 cycles, corresponding to a S_a value of $3S_m$ = 60.0 ksi (414 MPa) for [redacted] stainless steel over the temperature range of interest. Thus, condition (1) of NB-3222.4(d) is met.
2. Normal service pressure fluctuation cycles in the packaging result from diurnal fluctuations in ambient conditions (temperature and insolation). Thus, it is assumed that the packaging will experience one normal operating pressure fluctuation per day, or 7,300 cycles over its 20-year service life. A significant pressure fluctuation (SPF) is 89 psi (614 kPa) based on a bounding design pressure of 100 psi (690 kPa) gauge, S_a equal to 53.4 ksi (368 MPa) at 10^4 cycles per Table I-9.2 of Appendix I [2.11] of the ASME Code, and S_m equal to 20.0 ksi (138 MPa) for [redacted] stainless steel over the temperature range of interest. Due to the relatively large thermal mass of the package, variation of package temperatures sufficient to cause an internal pressure fluctuation of this magnitude are not considered credible. Thus, condition (2) of NB-3222.4(d) is met.
3. The temperature difference between any two adjacent points on the CCV shell during startup and shutdown is limited to 166°F (92°C). This is based on S_a equal to 82.2 ksi (567 MPa) for 1,040 startup shutdown cycles and the elastic modulus and mean coefficient of thermal

expansion for the CCV shell [redacted] stainless steel material at room temperature. The thermal evaluation of the packaging shows that temperature differences between any two adjacent points on the CCV is less than 166°F (92°C) under any NCT thermal condition. Thus, condition (3) of NB-3222.4(d) is met.

4. Normal operating temperature fluctuation cycles in the packaging result from diurnal fluctuations in ambient conditions (temperature and insolation). Thus, it is assumed that the packaging will experience one normal operating temperature fluctuation per day, or 7,300 cycles over its 20-year service life. The packaging's significant temperature fluctuation (STF) is over 100°F (38°C) based on S_a equal to 53.4 ksi (368 MPa) at 10^4 cycles and the elastic modulus and mean coefficient of thermal expansion for the CCV shell [redacted] stainless steel material at room temperature. Due to the relatively large thermal mass of the package, it is not credible that diurnal fluctuation in ambient temperature will cause any temperature fluctuations in the packaging that exceed the STF. Thus, condition (4) of NB-3222.4(d) is met.

5. Except for the closure bolts, the CCV does not have any dissimilar materials. Thus, condition (5) of NB-3221.9(d) is met.

6. The only significant cyclic mechanical loads, excluding pressure, that the packaging is subjected to during normal operation are those resulting from NCT vibration. It is assumed that the packaging will experience a total of 10^6 cycles of significant vibration loading (i.e., 2*g* vertical acceleration) over the 20-year service life. The value of S_a for austenitic stainless steels for 10^6 cycles is 18.3 ksi (126 MPa) per Table I-9.2 of Appendix I [2.11] of the ASME Code. Based on comparison to the results of the NCT end drop, the stresses in the packaging due to a 2*g* vertical vibration load are less than the S_a value for the total number mechanical load cycles. Thus, condition (6) of NB-3221.9(d) is met.

2.1.2.4.2 CCV Closure Bolts

The CCV closure bolts are subjected to cyclic loading due to startup-shutdown cycles of bolt preload, temperature, and pressure loading, normal fluctuation cycles of pressure and temperature, and cyclic loading due to vibration normally incident to transport. The CCV closure bolts are evaluated for fatigue failure due to cyclic loading using the methods of NB-3221.9(e) in accordance with the requirements of NB-3232(d)(2). In accordance with the requirements of NB-3232(d)(2)(d), a fatigue strength reduction factor of 4.0 is used for the CCV closure bolt fatigue evaluation. The analysis is conservatively based on the assumption that the CCV closure bolts will be replaced after 5 years of service and the packaging will be used for one shipment per week, for a total of 260 shipments over the life of the CCV closure bolts.

Startup-Shutdown Cycles

The CCV closure bolts are conservatively assumed to undergo 260 startup-shutdown cycles, assuming one shipment per week over a 5-year period. The maximum principal stress in the CCV closure bolt due to the combined direct tensile stress and torsional shear stress for maximum bolt preload, MNOP, reduced external pressure, and NCT heat loading (L.C. N2) is 70.3 ksi (485 MPa). The minimum stress in the CCV closure bolt for startup-shutdown cycles is zero. Thus, the alternating stress in the CCV closure bolts for startup shutdown cycles, including a fatigue reduction factor of 4 and an adjustment for the ratio of fatigue curve elastic modulus to the bolt elastic modulus at design temperature (i.e., 1.13), is 159.4 ksi (1099 MPa). The corresponding allowable number of startup-shutdown cycles is approximately 401 per Figure I-9.4 of Appendix I [2.11] of the ASME Code. Therefore, the CCV closure bolt usage factor for startup-shutdown cycles (U_1) is 0.65.

Thermal and Pressure Fluctuations – Normal Operating Cycles

Normal operating temperature and pressure fluctuations in the packaging result from diurnal ambient temperature fluctuations. The packaging is conservatively assumed to undergo one normal operating cycle for every day over a 5-year period, or 1,825 cycles. The pressure and temperature fluctuations are conservatively based on a diurnal ambient temperature range of 100°F (38°C) to -40°F (-40°C). The CCV bolt stresses are not affected by fluctuation of the internal pressure load because MNOP is not large enough to overcome the bolt preload. However, temperature fluctuations of the packaging produce alternating stress in the CCV bolts by differential thermal expansion between the bolt and lid materials.

The total tensile stress (direct plus bending) in the CCV closure bolt from temperature loading varies [redacted] for a stress fluctuation of 12.0 ksi (83 MPa). Thus, the alternating stress in the CCV closure bolts for normal operating thermal and pressure cycles, including a fatigue reduction factor of 4 and an adjustment for the ratio of fatigue curve elastic modulus to the bolt elastic modulus at design temperature (i.e., 1.13), is 27.2 ksi (188 MPa). The corresponding allowable number of normal operating cycles is approximately 19,640 per Figure I-9.4 of Appendix I [2.11] of the ASME Code. Therefore, the CCV closure bolt usage factor for normal operating thermal and pressure cycles (U_2) is 0.09 (1,825/19,640).

Vibration Cycles

The results of the CCV closure bolt evaluation show that NCT vibration loading results in only a [redacted] increase in the CCV closure bolt stress. Thus, the alternating stress in the CCV closure bolts for NCT vibration cycles, including a fatigue reduction factor of 4 and an

adjustment for the ratio of fatigue curve elastic modulus to the bolt elastic modulus at design temperature (i.e., 1.13), is S_{alt3} = 1.0 ksi (6 MPa). The value of S_a at 1E6 cycles is 5.3 ksi (37 MPa) per Figure I-9.4 of Appendix I [2.11] of the ASME Code. Since S_{alt3} is much lower that S_a at the endurance limit of 1E6 cycles, the usage factor for NCT vibration is insignificant (i.e., $U_3 = 0.00$).

Cumulative Usage Factor

The cumulative usage factor for cyclic loading of the CCV closure bolts is:

$$U = U_1 + U_2 + U_3 = 0.74$$

Since the cumulative usage factor is less than 1.0, the CCV closure bolt will not fail due to fatigue during their 5-year design life.

2.1.2.4.3 OSV Closure Bolts

The OSV closure bolts are subjected to cyclic loading due to startup-shutdown cycles of bolt preload, temperature, normal fluctuation cycles of temperature, and cyclic loading due to vibration normally incident to transport. The OSV closure bolts are not subject to high cycle (> 20,000) fatigue loading and do not require evaluation for fatigue failure per NF-3331.1 [2.7]. The OSV closure bolts will be replaced after 5 years of service and, assuming the packaging will be used for one shipment per week, the OSV closure bolts will be subjected to a total of 260 startup-shutdown cycles and 1,825 normal operating (diurnal fluctuations) cycles. Although the number of significant vibration cycles may exceed 20,000, vibration loading does not produce significant stress in the OSV closure bolts. Therefore, the OSV closure bolts will not fail due to fatigue during their 5-year design life.

2.1.2.5 Brittle Fracture

2.1.2.5.1 CCV Assembly

The CCV assembly, which is the containment vessel of the package, is designed in accordance with the fracture toughness requirements of Regulatory Guide 7.11 [2.13] and NUREG/CR 1815 [2.14] for Category I containers, since it is designed to transport normal form radioactive content with a maximum activity greater than 3,000 A_2 or greater than 30,000 Ci. The criteria for Category I containers assure that the fracture toughness is sufficient to arrest large cracks under dynamic loading and that general yielding will precede facture failure.

The entire CCV body and closure lid are fabricated from austenitic stainless steels, which do not undergo a ductile-to-brittle transition down to -40°F (-40°C) and, thus, do not need to be evaluated for brittle fracture. As stated in Regulatory Guide 7.11, “Since austenitic stainless

steels are not susceptible to brittle failure at temperatures encountered in transport, their use in containment vessels is acceptable to the staff and no tests are needed to demonstrate resistance to brittle fracture."

The CCV closure bolts are fabricated from [redacted] steel bolting material that is intended for low-temperature service. Per Section 5 of NUREG/CR-1815, bolts are generally not considered as fracture critical components because multiple load paths exist, and bolting systems are generally redundant. However, the SA-320, Grade L43 bolting material is required to have a minimum impact energy absorption of 20 ft-lbf (27 N-m) at a temperature of -101°C (-150°F). For purposes of comparison with the requirements of NUREG/CR-1815, the nil-ductility transition (NDT) temperature of the CCV closure bolts is calculated as follows. A fracture toughness value for [redacted] material is calculated using the following empirical relationship from Section 4.2 of NUREG/CR 1815:

$$K_{ID} = \sqrt{5C_vE} = 54 \text{ ksi-in}^{1/2} (59 \text{ MPa-m}^{1/2})$$

where C_v is 20 ft-lbf and E is 28.8×10^6 psi (199 MPa) at -150°F (-101°C) from Table TM-1, Material Group B of Section II, Part D, of the ASME Code [2.12].

The dynamic fracture toughness is conservatively translated to an equivalent NDT temperature by using the Design Reference KID curve provided in Figure 2 of NUREG/CR-1815. By interpolation, the temperature relative to NDT (i.e., T - NDT) is approximately 32°F (18°C). Accordingly, the NDT temperature is:

$$NDT = -150°F - (32°F) = -182°F (-119°C)$$

For Category I fracture critical components with a minimum section thickness of 1-inch and a yield strength of 100 ksi (690 MPa), Figure 3 of NUREG/CR 1815 gives the minimum offset "A" as approximately 44°F (7°C). Thus, for Lowest Service Temperature (LST) of -40°F (-40°C), the maximum NDT temperature value is:

$$T_{NDT} = \text{LST} - A = -40°F – (44°F) = -84°F (-64°C)$$

The closure bolts experience a ductile-to-brittle transition temperature at -182°F (-119°C), whereas the criterion of NUREG/CR-1815 prescribes a maximum NDT temperature of -84°F (-64°C). The 98°F (55°C) margin provides conservative assurance that brittle fracture will not occur in the CCV closure bolts.

2.1.2.5.2 OSV Assembly

The OSV assembly is the outer overpack that provides radiation shielding and structural protection for the CCV assembly, but the OSV assembly is not relied upon for containment. Accordingly, the OSV assembly is designed in accordance with the Category III fracture toughness requirements of NUREG/CR-1815 [2.14], which provide sufficient fracture toughness to prevent fracture initiation at minor defects typical of good fabrication practices.

Except for the OSV closure bolts and bolt anchors, all OSV assembly structural components are fabricated from ASTM A874 ductile cast iron. Material from each DCI casting shall be subjected to Charpy impact testing at -40°F (-40°C), as discussed in Section 8.1.5.2.

The OSV closure bolts and bolt anchors are fabricated from [redacted] steel. Per Section 5 of NUREG/CR-1815, bolts are generally not considered as fracture critical components because multiple load paths exist, and bolting systems are generally redundant.

2.1.2.5.3 Impact Limiter Assembly

The upper and lower impact limiters provide impact and thermal protection of the OSV and CCV, but the impact limiters do not provide containment. Accordingly, the impact limiter assemblies are designed in accordance with the Category III fracture toughness requirements of NUREG/CR-1815 [2.14], which provide sufficient fracture toughness to prevent fracture initiation at minor defects typical of good fabrication practices.

The upper and lower impact limiter shell assemblies are fabricated entirely from austenitic stainless steels, which does not undergo a ductile-to-brittle transition down to -40°F (-40°C) and, thus, does not need to be evaluated for brittle fracture.

[redacted] In accordance with the Category III requirements of NUREG/CR-1815, fracture toughness testing of normalized steel made to “fine grade practice” or better is not required.

2.1.2.5.4 Shield Inserts

The shield insert assembly (SIA) provides radiation shielding, but has no structural, thermal or containment function, except it is designed not to fail or collapse such that it would load the waste container. Accordingly, the SIA assembly is designed in accordance with the Category III fracture toughness requirements of NUREG/CR-1815 [2.14], which provide sufficient fracture toughness to prevent fracture initiation at minor defects typical of good fabrication practices.

2.1.3 Weights and Centers of Gravity

The weight and center of gravity of the package, including each of the major individual packaging subassemblies and contents, are summarized in Table 2.1-8. The reference point for the center of gravity is at the bottom centerline of the lower impact limiter assembly, as shown in Figure 2.1-2. The package has a total nominal weight of 31.3 kip (14,195 kg) and a center of gravity located at 41.6 inches (106 cm) above the bottom end of the lower impact limiter, which is close the geometric center of the package.

The nominal weight of the empty package is 24.0 kip (10,884 kg) per Table 2.1-8. The total weight of the packaging components may vary by ±2.5%, resulting in a weight range of 23.4 kip (10,612 kg) to 24.6 kip (11,156 kg) for the empty package. The highest gross package weight, including a 7.3 kip (3,311 kg) allowance for the payload, is 31.9 kip (14,467 kg).

The center of gravity of the CCV contents provided in Table 2.1-8 is assumed at the geometric center of the CCV cavity. The maximum possible axial shift of the center of gravity of the CCV contents is conservatively evaluated considering the CCV contents as a 7,300-pound (3,311 kg) solid steel right circular cylinder having the same diameter as the CCV cavity and shifted to the extreme ends of the cavity. This results in an 8.3-inch (21.1 cm) axial shift of the CCV contents center of gravity from the geometric center of the cavity, which shifts the package center of gravity by only 1.9-inch (4.9 cm).

2.1.4 Identification of Codes and Standards for Packaging

The package, which is designed to transport normal form radioactive content with a maximum activity greater than 3,000 A_2 and greater than 30,000 Ci, is designed, fabricated, tested, and maintained in accordance with codes and standards that are appropriate for transportation packages with Category I container contents. The codes and standards are selected based on guidance provided in Regulatory Guide 7.6 [2.4] and NUREG/CR-3854 [2.15].

The package containment system is designed in accordance with the applicable requirements of the ASME Code, Section III, Division 1, Subsection NB [2.5]. The non-containment structural components of the packaging are designed in accordance with the applicable requirements for plate- and shell-type Class 2 supports from the ASME Code, Section III, Division 1, Subsection NF [2.7]. The design criteria for the packaging is discussed in Section 2.1.2. The load combinations used in the packaging structural evaluation are developed in accordance with Regulatory Guide 7.8 [2.3], as discussed in Section 2.1.2.1. The buckling evaluation of the packaging cylindrical shells is performed in accordance with ASME Code Case N-284-1 [2.8], as discussed in Section 2.1.2.3. Fracture toughness of the packaging components is evaluated in

accordance with the requirements of Regulatory Guide 7.11 [2.13] and NUREG/CR-1815 [2.14] for Category I containers.

The packaging containment system is fabricated in accordance with the applicable requirements of Subsection NB of Section III, Division 1, of the ASME Code [2.5]. The non-containment structural components of the packaging are fabricated in accordance with the applicable requirements of Subsection NF [2.7] of the ASME Code for plate- and shell-type Class 2 supports.

The ductile cast iron components of the OSV are fabricated, installed, and tested in accordance with standard industry practices. Testing of the ductile cast iron material is performed to assure that it satisfies the requirements for chemical composition, tensile properties, fracture toughness, and microstructure. In addition, the soundness of the ductile cast iron material is demonstrated through ultrasonic or radiographic examination for internal defects and magnetic particle or liquid penetrant examination for surface defects.

The polyurethane foam material that fills the impact limiter base and lid shells is fabricated, installed, and tested in accordance with the foam vendors' standard practices. The foam segments are manufactured with the foam rise parallel to the longitudinal axis of the package and encased in the stainless steel shells. Foam specimens from each foam batch are tested to assure that the foam has the specified physical characteristics, including density, crush strength, flame retardancy, intumescences, and leachable chlorides.

Table 2.1-1 Load Combinations for Normal Conditions of Transport

NCT Test Condition	Initial Conditions[1]								
	Ambient Temperature[2]		Insolation[3]		Decay Heat		Internal Pressure[4]		Fabri-cation Stress[5]
	100°F	-40°F	Max.	Zero	Max.	Zero	Max.	Min.	
Hot Environment (100°F ambient)			X		X		X		X
Cold Environment (-40°F ambient)				X		X		X	X
Reduced External Pressure	X		X		X		X		X
Increased External Pressure		X		X		X		X	X
Vibration	X		X		X		X		X
		X		X		X		X	X
Free Drop	X		X		X		X		X
		X		X		X		X	X

Notes:

1. Initial packaging temperature distribution considered to be at steady-state.
2. Lower bound ambient temperature of -40°C conservatively used.
3. Maximum insolation in accordance with 10 CFR 71.71(c)(1).
4. Internal pressure is consistent with the other initial conditions being considered. Minimum internal pressure is taken as atmospheric pressure.
5. Stresses due to assembly of the major components of the packaging, including stresses due to bolt preload.

Table 2.1-2 Load Combinations for Hypothetical Accident Conditions

HAC Test Condition	Initial Conditions[1]								
	Ambient Temperature[2]		Insolation[3]		Decay Heat		Internal Pressure[4]		Fabri-cation
	100°F	-40°C	Max.	Zero	Max.	Zero	Max.	Min.	Stress[5]
Free Drop	X		X		X		X		X
		X		X		X		X	X
Puncture	X		X		X		X		X
		X		X		X		X	X
Thermal	X		X		X		X[6]		X

Notes:

1. Initial packaging temperature distributions are at steady-state.
2. Lower bound ambient temperature of -40°C conservatively used.
3. Maximum insolation in accordance with 10 CFR 71.71(c)(1).
4. Internal pressure is consistent with the other initial conditions being considered. Minimum internal pressure is taken as atmospheric pressure.
5. Stresses due to assembly of the major components of the packaging, including stresses due to bolt preload.
6. Maximum internal pressure for the HAC thermal condition includes increased pressure due to increased fill gas temperatures during the fire transient.

Table 2.1-3 Containment System Allowable Stress Design Criteria

Stress Type	Allowable Stress Limits[1]	
	NCT	HAC
Other Than Bolts		
Primary Membrane Stress Intensity (P_m)	S_m	Lesser of $2.4S_m$ and $0.7S_u$
Primary + Bending Stress Intensity (P_L or $P_L + P_b$)	$1.5S_m$	Lesser of $3.6S_m$ and S_u
Primary + Secondary Stress Intensity ($P_L + P_b + Q$)	$3.0S_m$	N/A[2]
Average Bearing Stress	S_y	Not required
Average Shear Stress	$0.6S_m$	$0.42S_u$
Bolts[3]		
Tension, Average Stress	S_m	Lesser of $0.7S_u$ and S_y
Shear, Average Stress	$0.6S_m$	Lesser of $0.42S_u$ and $0.6S_y$
Tension plus Shear	$R_t + R_s \leq 1$	$R_t + R_s \leq 1$
Maximum Stress Intensity[4]	$1.35S_m$	[5]

Notes:

1. Stress limits applicable for components and systems evaluated using elastic system analysis.
2. Evaluation of secondary stress is not required for HAC.
3. Per NUREG/CR-6007, Table 6.1 [2.28].
4. Limit for tension plus shear plus bending plus residual torsion for bolts having a minimum tensile strength, S_u, greater than 100 ksi.
5. Evaluation of maximum bolt stress not required for HAC.

Table 2.1-4 Non-Containment Component Allowable Stress Design Criteria

Stress Type	Allowable Stress Limits(1)	
	NCT	HAC
Other Than Bolts		
Primary Membrane Stress Intensity (P_m)	S_m	Greater of $1.2S_y$ and $1.5S_m$, but $\leq 0.7S_u$
Primary Membrane + Bending Stress Intensity (P_L or $P_m + P_b$)	$1.5S_m$	150% of P_m allowable
Average Bearing Stress	S_y	(2)
Average Shear Stress	$0.6S_m$	$0.42S_u$
Bolts		
Tensile Stress (f_t)	$F_{tb} = S_u/2$ (ferritic steels) $F_{tb} = S_u/3.33$ (austenitic steels)	Lesser of $0.7S_u$ and S_y(3)
Shear Stress (f_v)	$F_{vb} = 0.62S_u/3$ (ferritic steels) $F_{vb} = 0.62S_u/5$ (austenitic steels)	Lesser of $0.42S_u$ and $0.6S_y$
Combined Tensile & Shear Stress	$\frac{f_t^2}{F_{tb}^2} + \frac{f_v^2}{F_{vb}^2} \leq 1$	$\frac{f_t^2}{F_{tb}^2} + \frac{f_v^2}{F_{vb}^2} \leq 1$

Notes:

1. Stress limits applicable for components and systems evaluated using elastic system analysis.
2. Evaluation of secondary stress is not required for HAC.
3. Limit applies to average tensile stress across the entire bolt cross-section. For high-strength bolts (S_u > 100 ksi), the maximum value of tensile stress at the periphery of the bolt cross-section resulting from direct tension plus bending and excluding stress concentrations shall not exceed S_u.

Table 2.1-5 CCV Shell Buckling Geometric Parameters

Geometric Parameter	Value
Outside Diameter (in)	[redacted]
Inside Diameter (in)	[redacted]
Length, L (in)	[redacted]
Mean Radius, R (in)	[redacted]
Shell Thickness, t (in)	[redacted]
R/t	[redacted]
Unsupported Axial Length, l_ϕ (in)	[redacted]
Unsupported Circumferential Length, l_θ (in)	[redacted]
$M_\phi = l_\phi / \sqrt{Rt}$	[redacted]
$M_\theta = l_\theta / \sqrt{Rt}$	[redacted]
M = smaller of M_ϕ and M_θ	[redacted]

Table 2.1-6 CCV Shell Buckling Reduction Factors and Theoretical Buckling Stresses

Calculation	Parameter	Value
Capacity Reduction Factors (-1511)	$\alpha_{\phi L}$	0.210
	$\alpha_{\theta L}$	0.800
	$\alpha_{\phi\theta L}$	0.800
Plasticity Reduction Factors (-1610)	$\Delta=\alpha_{\phi L}*\sigma_{\phi eL}/\sigma_y$	9.38
	$\Delta=\alpha_{\theta L}*\sigma_{\theta eL}/\sigma_y$	5.14
	$\Delta=\alpha_{\phi\theta L}*\sigma_{\phi\theta eL}/\sigma_y$	12.99
	η_ϕ	0.107
	η_θ	0.195
	$\eta_{\phi\theta}$	0.046
Theoretical Buckling Values (-1712.1.1)	C_ϕ	0.605
	$\sigma_{\phi eL}$ (ksi)	964.4
	$C_{\theta r}$	0.087
	$\sigma_{\theta eL} = \sigma_{reL}$ (ksi)	138.7
	$C_{\theta h}$	0.082
	$\sigma_{\theta eL} = \sigma_{heL}$ (ksi)	130.7
	$C_{\phi\theta}$	0.220
	$\sigma_{\phi\theta eL}$ (ksi)	350.7

Table 2.1-7 CCV Shell Allowable Buckling Stresses

Buckling Regime	Stress Type	Allowable Buckling Stress (ksi)	
		NCT	HAC
Elastic Buckling	Axial Compression, σ_{xa}	101.3	151.1
	Hydrostatic Pressure, σ_{ha}	52.3	78.0
	Hoop Compression, σ_{ra}	55.5	82.8
	In-Plane Shear, $\sigma_{\tau a}$	140.3	209.4
Inelastic Buckling	Axial Compression, σ_{xc}	10.8	16.2
	Radial External Pressure, σ_{rc}	10.8	16.1
	In-Plane Shear, $\sigma_{\tau c}$	6.5	9.6

Table 2.1-8 Package Weight and Center of Gravity Summary

Package Component or Assembly	Weight(1) (kip)	Center of Gravity(2) (in)
CCV Assembly	3.1	50.4
CCV Body Assy.	*2.1*	*42.3*
CCV lid Assy. & Bolts	*1.0*	*66.7*
OSV Assembly	16.3	40.0
OSV Body Assy.	*14.8*	*36.9*
OSV Closure Lid Assy. & Bolts	*1.5*	*70.7*
Lower Impact Limiter Assy.	2.3	13.2
Upper Impact Limiter Assy.	2.3	70.0
Empty Package	**24.0**	**41.7**
CCV Contents(3)	7.3	41.3(4)
[redacted] *SIA*	*1.44*	---
[redacted] *SIA*	*2.96*	---
[redacted] *SIA*	*4.91*	---
Waste in Secondary Container	*(3)*	---
Package Gross Weight	**31.3**	**41.6**

Notes:

1. Nominal weights of packaging components are rounded to the nearest 1/10th kip (100 pound) increment.
2. Vertical distance from the bottom end centerline of the lower impact limiter to the center of gravity of the individual packaging subassembly or assembly, as shown in Figure 2.1-2.
3. Maximum combined weight of CCV contents, including waste content in a secondary container, internal structures (e.g., SIA and dunnage or cribbing, as required), shall not exceed 7.3 kip.
4. Possible variation in the CCV content mass distribution within the CCV cavity does not significantly shift the package center of gravity.

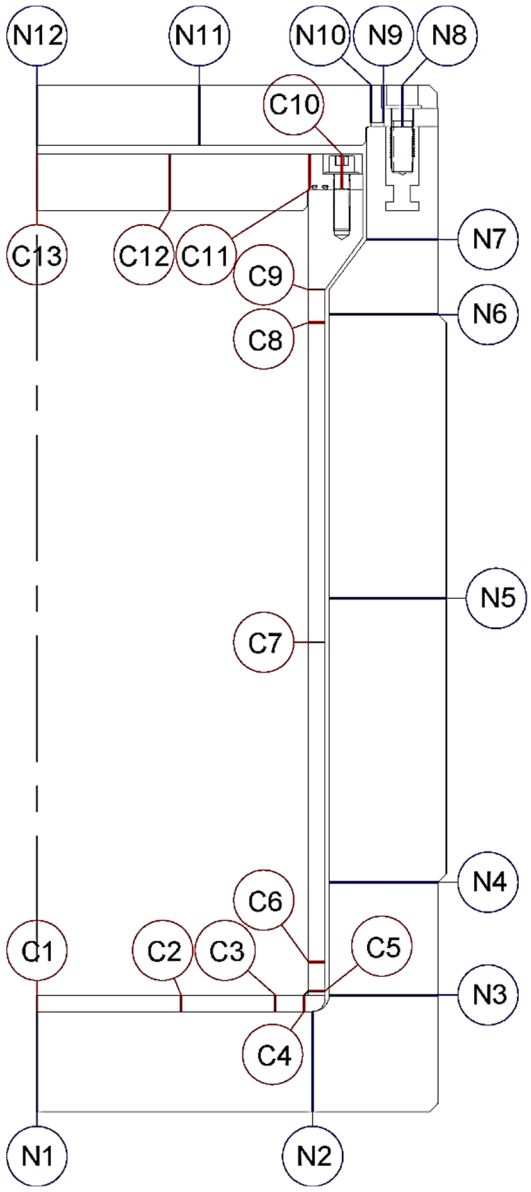


Figure 2.1-1 CCV and OSV Stress Evaluation Locations

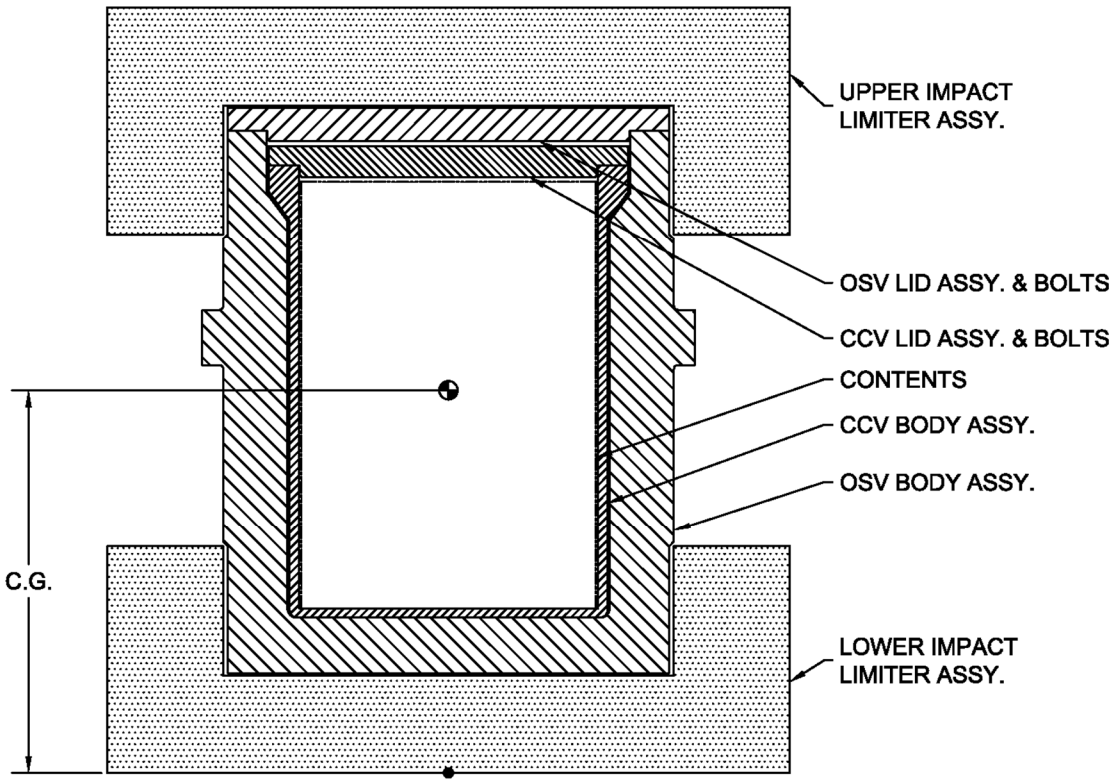


Figure 2.1-2 Package Mass Properties Schematic

2.2 Materials

2.2.1 Material Properties and Specifications

The specifications for the packaging materials of construction are summarized in Table 2.2-1. The mechanical properties of the packaging materials that are used in the structural evaluation are described in this section. The material properties for all steel and cast iron structural components of the packaging are described in Section 2.2.1.1. The crush strength properties of the impact limiter foam material are described in Section 2.2.1.2.

2.2.1.1 Structural Materials

The structural components of the packaging are fabricated from stainless steel, carbon steel, ductile cast iron, and alloy steel bolting material. Type [redacted] austenitic stainless steels in the form of plates [redacted] forgings [redacted], or bars and shapes [redacted] are used to fabricate the structural components of the CCV and impact limiter. The OSV body (including the lifting trunnions and impact limiter attachment brackets) and lid are fabricated from ductile cast iron conforming to [redacted]. The socket head cap screws used for the CCV and OSV closure bolts conform to [redacted] steel specifications, respectively. The OSV bolt anchors, which are cast into the OSV body, consist of a sleeve nut and an anchor bolt. The anchor bolts are made from the same material as the OSV closure bolts. The sleeve nut material is [redacted] steel, the compatible nut material for the OSV closure bolt and anchor bolt steel. Table 2.2-1 provides a summary of the material specifications used for the different structural components of the packaging and the corresponding tables that provide the material properties.

The structural evaluation of the packaging is performed using mechanical properties of materials that are appropriate for the anticipated service conditions. The temperature range of interest for NCT is -40°F (-40°C) to 500°F (260°C). Temperature dependent mechanical properties for the structural material of the packaging, including design stress intensity (S_m) or allowable stress (S), yield strength (S_y), tensile strength (S_u), modulus of elasticity (E), and mean coefficient of thermal expansion (α), are summarized in Table 2.2-2 through Table 2.2-7.

2.2.1.2 Impact Limiter Energy-Absorbing Materials

The impact limiters are filled with rigid, closed-cell polyurethane foam. [redacted] The dynamic stress versus strain

data for the polyurethane foam materials, used for the NCT and HAC free drop test evaluations, are developed based on data provided by a foam manufacturer [2.19]. Upper-bound and lower-bound dynamic stress-versus-strain curves are developed for each crush direction, i.e., parallel or perpendicular to the direction of foam rise; considering temperature effects, strain rate, and manufacturing tolerance on foam crush strength. The minimum and maximum foam temperatures considered are -40°F (-40°C) and 180°F (82°C), respectively. These temperatures represent the range of temperatures the foam will experience under all initial conditions for the NCT and HAC free drop tests. The nominal static crush strength of foam at the NCT cold temperature of -40°F (-40°C) and the NCT hot temperature of 180°F (82°C), both parallel and perpendicular to the direction of rise, are based on test data provided by the foam manufacturer [2.19].

The average static compressive strength of the [redacted] at room temperature is required to be between 80% and 110% of the nominal value for crushing parallel and perpendicular to the direction of foam rise. The average static compressive strength of the side/corner foam at room temperature is required to be at least 85% of the nominal value for the lower-bound [redacted] and no more than 110% of the nominal value for the upper-bound [redacted] for crushing parallel and perpendicular to the direction of foam rise. The dynamic crush strength of foam is calculated from the static crush strength stress-strain data, adjusted for temperature effects and fabrication tolerance, using the dynamic crush strength regression coefficients provided by the foam manufacturer [2.19].

The data shows little difference between the crush strength due to crush direction. Therefore, the foam is treated as an isotropic material in the drop analysis using stress-strain curves that bound the data for parallel and perpendicular-to-rise directions. The stress-strain curves used to evaluate the upper-bound cold conditions are based on the maximum stress values from the parallel and perpendicular-to-rise directions, whereas the stress-strain curves used to evaluate the lower-bound hot conditions are based on the minimum stress values from the parallel and perpendicular-to-rise directions. The resulting upper-bound and lower-bound dynamic crush strength-versus-strain curves of end and side/corner foam materials are summarized in Figure 2.2-1 and Figure 2.2-2, respectively.

2.2.2 Chemical, Galvanic or Other Reactions

The packaging's materials of construction, consisting primarily of stainless steel, coated carbon steel and cast iron, and polyurethane foam, will not cause significant chemical, galvanic, or other reactions in the operating environment. No significant interactions are expected to occur among the contents, which consist of fuel waste or TRU waste contained in secondary containers (e.g.,

drums or boxes) or irradiated fuel waste (IFW), between the contents of the package and the packaging materials to which they are exposed, or among the packaging components. The packaging materials have been used in other radioactive material (RAM) packaging for transport of similar contents without incident. This ensures the packaging integrity will not be compromised by any chemical, galvanic, or other reaction. Therefore, the requirements of 10 CFR 71.43(d) are met.

2.2.2.1 Reactions Among Contents

For TRU waste contents, the requirements for chemical compatibility discussed in Section 4.5.3 preclude potential adverse reactions resulting from incompatible combinations of the TRU waste groups. With respect to potentially significant chemical, galvanic, or other reactions among the TRU waste contents, the primary reaction of concern for plastics and other polymer waste materials at elevated temperatures is increased radiolytic gas generation rates. As discussed in Section 4.5.4.1, *Temperature Adjustments*, the G values used for the TRU waste contents are adjusted for the temperature effect on radiolytic gas generation in accordance with NUREG/CR-6673. Furthermore, the maximum temperature of the waste contents given in Tables 3.1-3 and 3.1-4 for NCT and HAC, respectively, are well below the 302°F (150°C) threshold temperature at which gas would be generated through thermal decomposition of plastics and other polymer waste materials in air.

There is also no potential for auto-ignition of TRU waste contents, including nonradioactive pyrophoric material, under NCT and/or HAC. All nonradioactive pyrophoric material is required to be reacted (or oxidized) and/or otherwise rendered nonreactive prior to placement in the payload container (i.e., secondary container, typically a drum). In addition, the auto-ignition temperatures of materials included in TRU waste, such as paper, cloth, wood, thermoplasitcs, rubbers and alcohols, are all higher than 450°F [2.31][2.32]; which is higher than the maximum temperatures of the contents for NCT and HAC.

No significant chemical, galvanic, or other reactions will occur among the IFW contents in air, helium gas or water environments.

2.2.2.2 Reactions Between Contents and Packaging

The exposed surfaces of the impact limiter assemblies and the CCV assembly are all constructed of [redacted] austenitic stainless steel, with high corrosion resistance in the operating environments of the packaging. Radioactive contents are packaged in secondary containers, such as drums or liners, which limits the chemical interaction between the payload and CCV. In

theory TRU waste may contain very small amounts of halides, specifically hydrogen chloride (HCl) gas that could originate from radiolysis of polyvinyl chloride or halogenated organics within the TRU waste, with the potential to cause stress corrosion cracking of the CCV stainless steel material. However, the nature of the TRU waste and the conditions under which it will be transported are expected to preclude the possibility of producing any significant quantities of free HCl gas inside the secondary containers, and the small quantities of free HCl gas are likely to be absorbed by the moisture content of the waste materials and retained inside the secondary containers. This was demonstrated by gas sampling programs on drums of newly generated contact handled TRU waste at Idaho National Engineering Laboratory (INEL) [2.29] and Rocky Flats Plant [2.30] that did not detect any HCl gas in the drum headspace or any layers of confinement within the waste. Since corrosives are prohibited from the payload, there are no chemical, galvanic, or other reactions between the contents and the CCV of concern.

No significant chemical, galvanic, or other reactions between the packaging and the IFW contents in air, helium gas or water environments.

2.2.2.3 Reactions Among Packaging

The OSV ductile cast iron material and SIA carbon steel surfaces are coated with Cycloaliphatic Amine Epoxy coating. This epoxy mastic coating, which is commonly used in the nuclear industry for similar applications, is highly resistant to chemical reactions and has very good abrasion resistance. The coated surfaces of the OSV assembly contact the stainless steel surfaces of the CCV and impact limiters. The coated surfaces of the SIA assembly contact the stainless steel surfaces of the CCV. Therefore, no chemical, galvanic, or other reactions are expected between the OSV coating or SIA coating and stainless steel.

The polyurethane foam material used for the cores of the impact limiters has a long history of use in RAM packages without any adverse reactions. The foam material is very low in free-halogen content and leachable chlorides. The closed-cell polyurethane foam material is sealed inside the cavity of the impact limiter stainless steel shells in a dry environment. In the unlikely event moisture was to enter the impact limiter cavity, it could not penetrate the closed-cell structure of the foam to cause leaching of chlorides. Therefore, no chemical, galvanic, or other reactions are expected between the foam and stainless steel.

The [redacted] O-ring material that contacts the stainless steel base material of the CCV contains no corrosives to adversely affect the packaging. This material is organic in nature and has not had any chemical, galvanic, or other reactions with stainless steel.

2.2.3 Effects of Radiation on Materials

The packaging is designed using materials to withstand damaging effects from radiation. Durable materials of construction such as austenitic stainless steel, carbon steel, ferritic bolting steel, and ductile cast iron are unaffected by the radiation levels in this package.

The polyurethane foam material used for the impact limiter cores is unaffected by gamma radiation exposure up to 2×10^8 rad, equivalent to 1,000 rad/hour for a period of 20 years. At radiation exposure up to 2×10^8 rad, testing shows no effect on density or crush strength ([2.19], Table 4). Furthermore, the resistance of the polyurethane foam material to water absorption is unaffected by radiation exposure up to 1×10^7 rad ([2.19], Table 5).

Fluorocarbon polymer O-ring material has good radiation-resistance properties [2.19]. Radiation exposure below 10^6 rad, a level attained only after many years of operation, produces no change to the physical properties of the O-ring material. Therefore, normal wear, as opposed to radiation exposure is the main factor affecting their replacement frequency.

The O-rings are coated with a thin film of silicone-based lubricant to help protect the O-ring from damage by abrasion, pinching, or cutting. The lubricant also helps to seat the O-ring properly and protect the polymer from environmental damage. Because the O-ring lubricant is frequently cleaned and replaced, and because most of the lubricant's benefit occurs during installation, radiation damage is not a concern.

A nickel-based thread lubricant is specified for threaded fasteners. This material is commonly used for nuclear applications and is suitable for use in radiation environments. None of the packaging fasteners are in high exposure areas, and the lubricant is frequently cleaned and replaced, so the lubricant is not subject to radiation damage.

Table 2.2-1 Packaging Structural Material Specifications

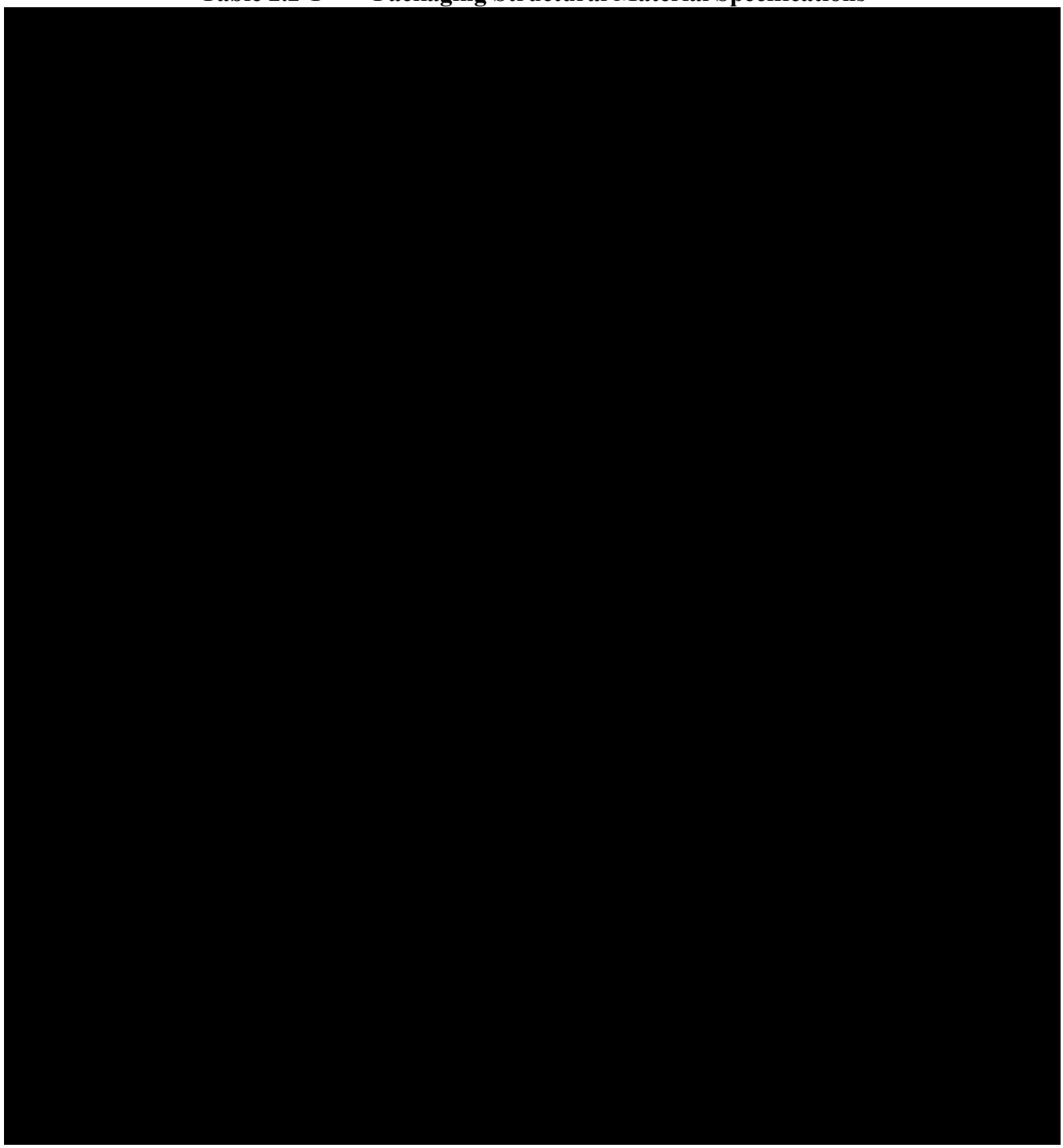


Table 2.2-2

[redacted]

Table 2.2-3

[redacted]

Table 2.2-4 [redacted]

[redacted]

Table 2.2-5 [redacted]

[redacted]

Table 2.2-6 [redacted]

[redacted]

Table 2.2-7 [redacted]

[redacted]

Table 2.2-8

[redacted]

Table 2.2-9

[redacted]

Figure 2.2-1 [redacted] Upper and Lower-Bound Dynamic Stress-Strain Curves

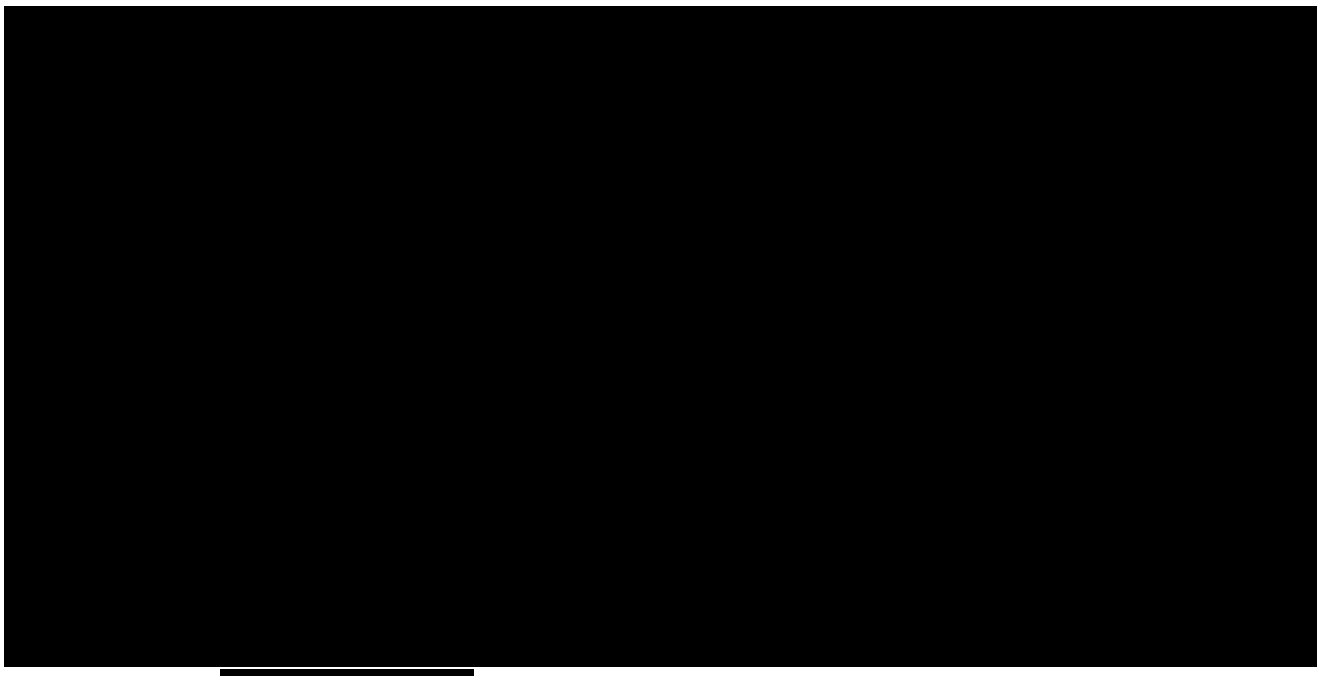


Figure 2.2-2 [redacted] Upper and Lower-Bound Dynamic Stress-Strain Curves

THIS PAGE INTENTIONALLY LEFT BLANK

2.3 Fabrication and Examination

2.3.1 Fabrication

Fabrication of the packaging is performed under NAC's 10 CFR 71, Subpart H quality assurance program, NRC approval number 0018. The packaging containment system is fabricated in accordance with the applicable requirements of ASME Subsection NB [2.5]. Use of an NPT Certificate Holder and an Authorized Inspection Agency is not required for the construction of the packaging containment system. The non-containment structural components of the packaging are fabricated in accordance with the applicable requirements of ASME Subsection NF [2.2] for plate- and shell-type Class 1 supports. Standard industry practices are used for the fabrication of the OSV assembly ductile cast iron components and the impact limiter assembly polyurethane foam cores.

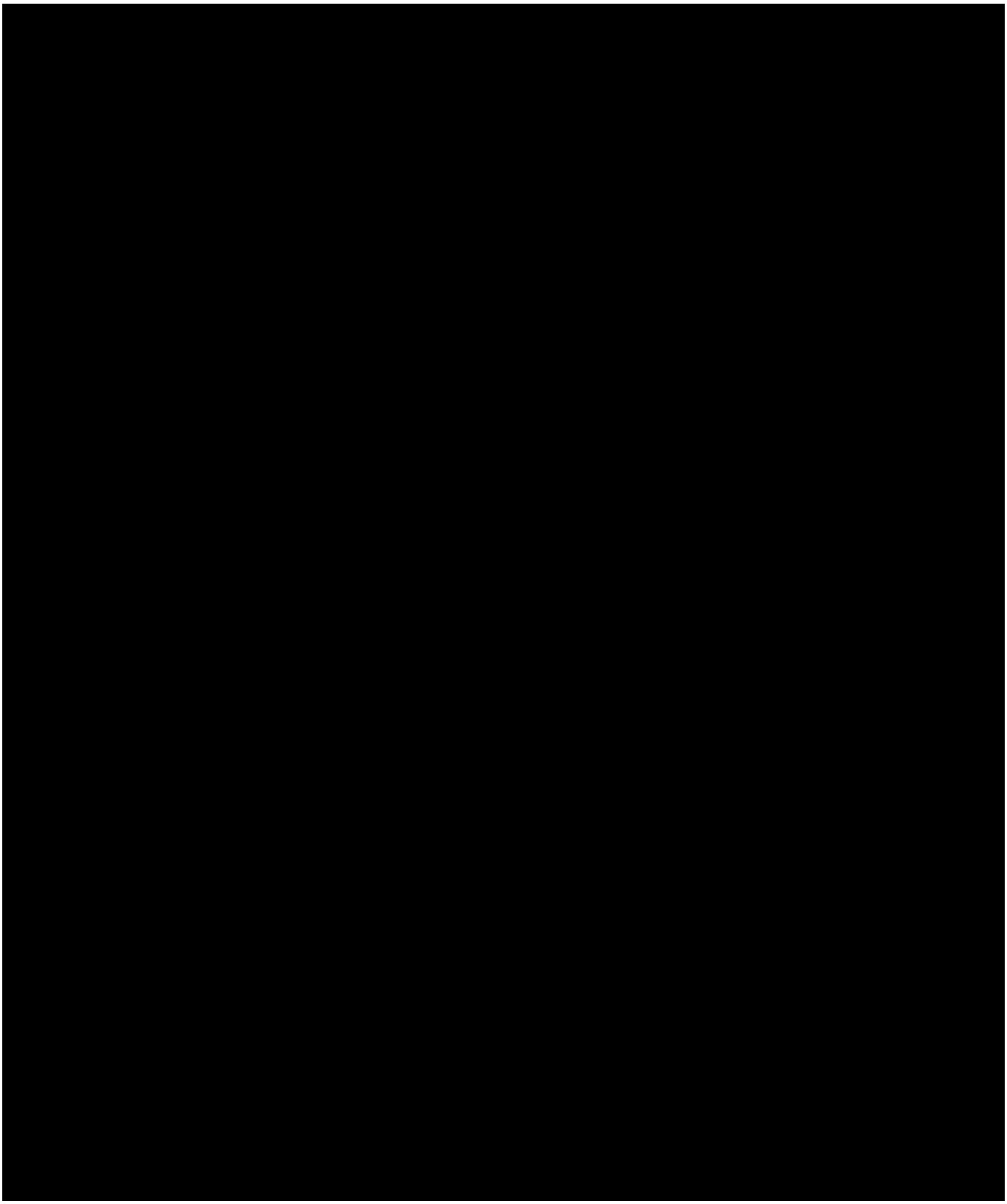
All components that form the packaging containment system are fabricated from materials permitted by ASME Subsection NB [2.5] and included in ASME Section II, Part D [2.12]. All other non-containment structural components of the packaging are fabricated from ASTM materials that are equivalent to ASME materials, as permitted by NUREG/CR-3854 [2.15]. The quality category of the weld material is required be equal to or greater than the higher quality category of the components being joined. A certified material test report (CMTR) is provided for all steel materials, including weld filler metals, used to fabricate the packaging containment system.

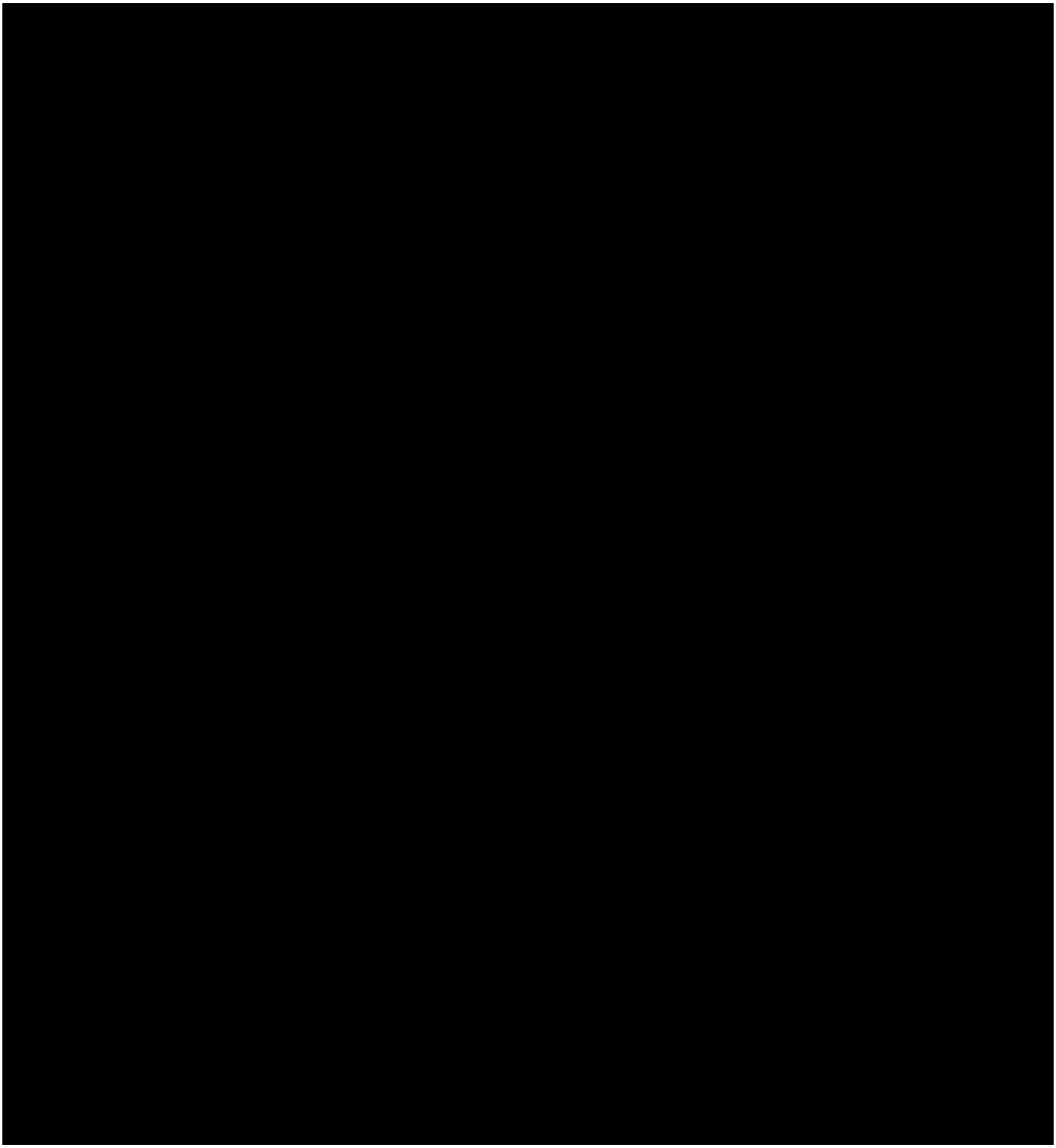
Consumables, such as threaded inserts and elastomeric O-rings, are procured from commercial suppliers and commercially dedicated in accordance with the requirements of the NAC QA program, commensurate with their safety functions.

All Category A and B materials, components, and assemblies used for the fabrication of the packaging, including the weld filler metal, are labeled to maintain control and traceability of materials throughout the fabrication process. Marking of materials, components, and assemblies is done using methods that do not result in harmful contamination or sharp discontinuities or infringe upon the minimum required material thickness.

All operations associated with the fabrication and assembly of the packaging are included in written shop instructions, e.g., fabrication travelers and/or procedures. All welding is performed in accordance with a written welding procedure specification (WPS) that is qualified in accordance with the applicable requirements of the ASME Code. All personnel performing welding are qualified to use the welding procedure, and their qualifications are documented in

accordance with the applicable requirements of Section IX of the ASME Code [2.21].

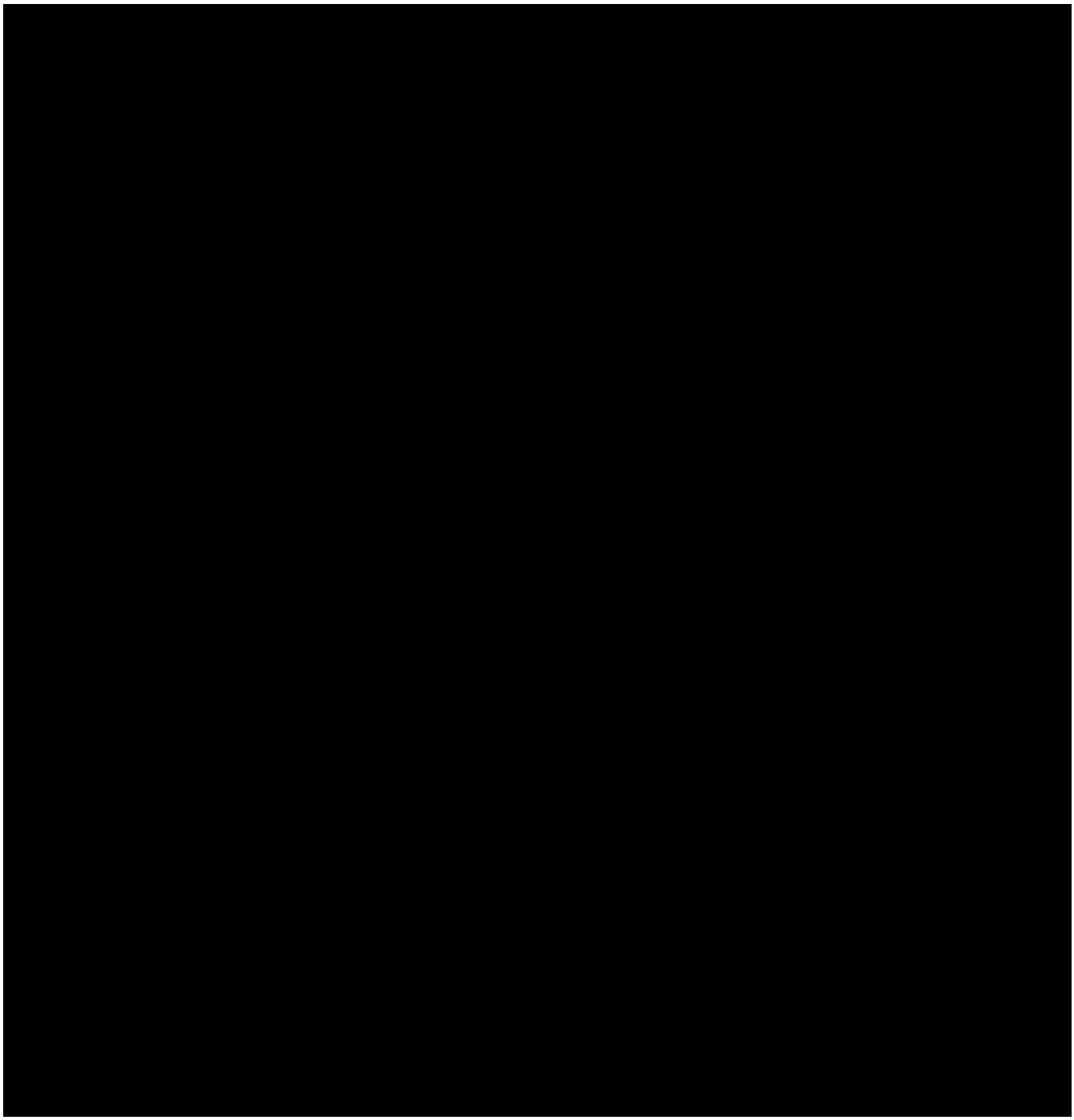




2.3.2 Examination

Examination and testing of the packaging is performed under NAC's NRC approved QA program. The components and assemblies of the packaging are inspected to assure that the packaging satisfies the dimensional requirements shown on the general arrangement drawings in Appendix 1.3.3 and are examined using non-destructive techniques to assure quality of

workmanship. In addition, materials, components, and assemblies are tested to assure that they have the required critical characteristics and that they satisfy the acceptance criteria for all required functional tests. All operations associated with the examination and testing of the packaging are included in written shop instructions, e.g., fabrication travelers and/or procedures, and performed by personnel that are trained and qualified, or approved, in accordance with the requirements of the NAC QA program and the requirements of the applicable codes and standards using calibrated measuring and test equipment (M&TE). Witness and hold points are included in the written shop instructions for activities that require QA inspection or oversight. Copies of all written shop instructions, personnel training and qualification records, and M&TE calibration records are maintained with the final records package.



THIS PAGE INTENTIONALLY LEFT BLANK

2.4 General Requirements for All Packages

2.4.1 Minimum Package Size

In accordance with the requirement of 10 CFR 71.43(a), the smallest overall dimension of a package may not be less than 10 cm. The OPTIMUS®-H package has an overall height of approximately 83.2 inches (211 cm) and an outside diameter of 74.2 inches (188 cm). Therefore, the package meets the minimum package size requirement of 10 CFR 71.43(a).

2.4.2 Tamper-Indicating Feature

In accordance with the requirement of 10 CFR 71.43(b), the outside of a package must incorporate a feature, such as a seal, that is not readily breakable and that, while intact, would be evidence that the package has not been opened by unauthorized persons. Wire cable tamper-indicating seals or similar devices are attached to the upper and lower impact limiter attachments after the impact limiters are secured to the OSV such that the impact limiters cannot be removed from the OSV without damaging the tamper-indicating seals or the package. The location of the seal and its materials of construction minimize the potential for accidental damage during transport. Thus, the package satisfies the tamper indicating feature requirements of 10 CFR 71.43(b). The tamper indicating seal is not required to be installed for empty shipments.

2.4.3 Positive Closure

In accordance with the requirement of 10 CFR 71.43(c), the package must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by a pressure than may arise within the package. The CCV is completely enclosed inside the OSV, which is also enclosed on the top and bottom ends by the upper and lower impact limiters, which include tamper indicating seals, as discussed in Section 2.4.2. The tamper indicating seals prevent the upper and lower impact limiters from being unintentionally removed from the package. Furthermore, both the OSV and CCV include closure lids that are secured by closure bolts. Since tools are required to remove these closure bolts, the package containment system cannot be unintentionally opened. The containment system does not include any covers, valves, or other access that could be inadvertently opened.

The package containment system is evaluated for internal pressure loads that arise during NCT and HAC in Section 2.6 and Section 2.7, respectively. The evaluations demonstrate that the CCV closure bolts satisfy the applicable allowable stress design criteria and that the containment seal remains intact under NCT and HAC. Hence, the package containment system satisfies the positive closure requirements of 10 CFR 71.43(c).

THIS PAGE INTENTIONALLY LEFT BLANK

2.5 Lifting and Tie-Down Standards for All Packages

2.5.1 Lifting Devices

In accordance with the requirements of 10 CFR 71.45(a), the lifting attachments that are structural parts of the package are designed with a minimum factor of safety of three against yield when used to lift the package in the intended manner. The lifting attachments are also designed so that failure of any lifting device under excessive load would not impair the ability of the package to meet the other requirements of 10 CFR 71 Subpart E.

The lifting attachments of the OPTIMUS®-H package are designed in accordance with the requirements of ANSI N14.6 [2.25] for special lifting devices for critical lifts. Because the package lifting attachments do not include dual-load paths, the lifting attachments are designed to lift the package without generating a combined shear stress or maximum tensile stress at any point in the lifting attachment more than $S_y/6$ or $S_u/10$. In accordance with ANSI N14.6, the shear stress and tensile stress due to direct load are taken as an average value over the cross-section, and tensile stress due to bending loads is assumed to vary linearly over the cross-section. The ANSI N14.6 design limits for lifting devices are lower than the criteria of 10 CFR 71.45(a) and, therefore, compliance with ANSI N14.6 also demonstrates compliance with 10 CFR 71.45(a).

The package is designed to be lifted vertically by the two OSV lifting trunnions using a lifting fixture with vertical elements that engage the trunnion shafts. To lift the package by the OSV lifting trunnions, the upper impact limiter must be removed from the package to provide access to the lifting. The maximum weight of the OSV, CCV, and heaviest CCV contents (i.e., the package gross weight less the weight of the upper impact limiter) is less than 30,000 pounds (13,608 kg). The bounding weight is conservatively increased by an additional 15% to account for possible dynamic amplification due to crane hoist motion. Therefore, a design lift load of 34.5 kip (15,649 kg), or 17.25 kip (7,823 kg) per trunnion, is conservatively used for the evaluation of the OSV lifting trunnions.

The vertical reaction load on the trunnion is conservatively assumed to be applied at the free end of the trunnion [redacted] The linear bending stress (f_b) and average shear stress (f_v) at the base of the trunnion shaft, which are calculated using classical hand-calculations are 1.8 ksi (12 MPa) and 0.6 ksi (4 MPa), respectively. The allowable tensile stress for the ductile cast iron base material, based on the ductile cast iron yield strength of 25.4 ksi (175 MPa) and tensile strength of 43.4 ksi (299 MPa) at a bounding design temperature of 200°F (93°C), is 4.2 ksi (29 MPa). The allowable shear stress for lifting devices

is taken as 60% of the allowable tensile stress, or 2.5 ksi (17 MPa). The minimum design margins for bending and shear stress in the trunnion are +1.33 and +3.17, respectively. Therefore, the lifting trunnion satisfies the stress limits of 10 CFR 71.45(a).

The OSV shell at the location of the trunnions is solid ductile cast iron [redacted] The stresses in the OSV shell due to the lifting load will be much lower than the stresses at the base of the trunnion. Therefore, it is concluded that excessive loading would result if structural failure at the base of the trunnion rather than in the OSV shell. Because the OSV trunnions are not relied upon for other safety functions, their loss would not impair the ability of the package to meet the other requirements of 10 CFR 71 Subpart E. Therefore, the over-load requirement of 10 CFR 71.45(a) is satisfied.

In accordance with the requirements of 10 CFR 71.45(a), any other structural part of the package that could be used to lift the package must be capable of being rendered inoperable for lift the package during transport or must be designed with strength equivalent to that required for lifting attachments. Therefore, the OSV tie-down lugs, which may also be used to lift the package, are evaluated to demonstrate compliance with the lifting requirements of 10 CFR 71.45(a).

The package may be lifted by two diametrically-opposed tie-down lugs. The allowable lug loads for single plane fracture (hoop tension failure) and double shear plane (shear tear-out) are calculated in accordance with Section 3-3.3 of ASME BTH-1-2005 [2.26] based on the ANSI N14.6 stress limits of $S_y/6$ and $S_u/10$.

The results show that the minimum allowable lug load is 19.8 ksi (137 MPa) for single plane fracture (hoop tension failure) based on a yield strength of ductile cast iron of 25.4 ksi (175 MPa) at 200°F (93°C), compared to the design lift load of 17.25 kip (78 kN). The maximum bearing stress between the shackle pin and the tie-down lug due to the 17.25 kip (78 kN) design lift load is 3.1 ksi (21 MPa). In accordance with ASME BTH-1-2005 and ANSI N14.6, the allowable bearing stress is taken as $1.25 \times S_y/6$, or 5.3 ksi (37 MPa) for ductile cast iron at 200°F (93°C). The corresponding minimum design margin of the OSV tie-down lug for shear tear-out and bearing stress are +0.15 and +0.71, respectively. Therefore, the tie-down lug satisfies the stress limits of 10 CFR 71.45(a). Furthermore, under excessive loading the tie-down lug will fail due to shear tear-out, which would not impair the ability of the package to meet the other requirements of 10 CFR 71 Subpart E. Therefore, the over-load requirement of 10 CFR 71.45(a) is satisfied when the package is lifted by the OSV tie-down lugs.

2.5.2 Tie-Down Devices

In accordance with the requirements of 10 CFR 71.45(b), the package tie-down devices are designed to withstand a static force applied to the package center gravity with a 2g vertical load component, a 5g lateral load component, and a 10g longitudinal (i.e., horizontal component along the direction in which the vehicle travels) load component, without generating stress in any material of the package more than its yield strength.

The reaction loads on the package tie-downs due to the 2g vertical load, 5g lateral load, and a 10g longitudinal loads are determined using the principal of static equilibrium assuming that the package is chocked to prevent the bottom end from sliding on the conveyance and that the package rotates as a rigid-body about the edge of the lower impact limiter. The maximum reaction loads in tiedowns resulting from combination of the 10*g* longitudinal load and 2*g* vertical load and from the 5*g* lateral load are determined separately for tie-down angles ranging from 45° to 60° from horizontal, and the tie-down forces are combined by SRSS to determine the maximum tie-down load. The results show that the maximum tie-down tensile force is 131 kip (583 kN), resulting from the minimum tiedown angle of 45°.

[redacted]

The results of the tie-down stress analysis show that the minimum design margin for shear tear-out stress in the lug is less than the minimum design margin for combined tensile and shear stress at the base of the tie-down lug. Therefore, under excessive loading, the lug will fail due to shear tear-out instead of failure at the lug base. Because the OSV tie-down lugs are not relied upon for other safety functions, their loss would not impair the ability of the package to meet the other requirements of 10 CFR 71 Subpart E. Therefore, the over-load requirement of 10 CFR 71.45(b)(3) is satisfied when the package is tied down by the OSV tie-down lugs.

In accordance with the requirements of 10 CFR 71.45(b)(2), any other structural part of the package that could be used to tie-down the package must be capable of being rendered inoperable for tying down the package during transport or must be designed with strength equivalent to that required for tie-down devices. Therefore, the OSV trunnions, which may also be used to tie-down the package, are evaluated to demonstrate compliance with the tie-down requirements of 10 CFR 71.45(b).

[redacted] The maximum tie-down load resulting due to the 2g vertical load, 5g lateral load, and a 10g longitudinal loads is calculated using the same approach described above. The results show that the maximum tie-down load is 215 kip (956 kN).

[redacted]

[redacted] The stresses in the OSV shell due to the tie-down load will be much lower than the stresses at the base of the trunnion. Therefore, by inspection, it is concluded that excessive loading would result in structural failure at the base of the trunnion rather than in the

OSV shell. Because the OSV trunnions are not relied upon for other safety functions, their loss would not impair the ability of the package to meet the other requirements of 10 CFR 71 Subpart E. Therefore, the over-load requirement of 10 CFR 71.45(b)(3) is satisfied when the package is tied down by the OSV trunnions.

Figure 2.5-1 Package Tie-Down Configuration

Figure 2.5-2 Alternate Package Tie-Down Configuration (Using OSV Trunnions)

This page intentionally left blank.

2.6 Normal Conditions of Transport

This section presents the structural evaluation of the package that demonstrates compliance with the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a)(1) when subjected to the NCT tests specified in 10 CFR 71.71. In accordance with 10 CFR 71.71(a), the package is required to be evaluated for each NCT test individually based on the most unfavorable initial conditions, including an ambient temperature between -20°F (-29°C) and 100°F (38°C) and an internal pressure between zero and the MNOP. The package is conservatively evaluated for NCT using a lower bound initial ambient temperature of -40°F (-40°C). The structural evaluation shows that there would be no loss or dispersal of radioactive contents, no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging.

2.6.1 Heat

In accordance with 10 CFR 71.71(c)(1), the package is subjected to an ambient temperature of 100°F (38°C) in still air and insolation. The packaging maximum internal pressure and temperatures resulting from NCT heat conditions are summarized in Section 2.6.1.1. Differential thermal expansion between the various components of the package under NCT heat loading is evaluated in Section 2.6.1.2. The packaging stresses due to NCT heat loading are evaluated in Section 2.6.1.3. The results of the NCT heat structural evaluation demonstrate that the packaging satisfies the applicable structural design criteria.

2.6.1.1 Summary of Pressures and Temperatures

The maximum temperatures of the packaging components for NCT thermal conditions from Chapter 3 are summarized in Table 3.1-3. For fuel waste contents having a maximum decay heat load of 1,500W with helium fill gas in the CCV cavity, the maximum package temperatures result from the case with an ambient air temperature of 100°F (38°C) and insolation. For this case the maximum temperature of the OSV and CCV assemblies are 221°F (105°C) and 288°F (142°C), respectively. For TRU waste contents having a maximum decay heat load of 200W with helium fill gas in the CCV cavity, the maximum temperature of the OSV and CCV assemblies are 166°F (74°C) and 178°F (81°C), respectively. For TRU waste contents having a maximum decay heat load of 50W and air in the CCV cavity, the maximum temperature of the OSV and CCV assemblies are 148°F (64°C) and 150°F (66°C), respectively. The allowable stress intensities used for the evaluation of the OSV and CCV are conservatively based on an upper bound temperature of 300°F (149°C) or higher. The only exception to this is the allowable stresses for the OSV lifting and tiedown attachments, which are based on an upper bound temperature of 200°F (93°C) for the outside of the OSV shell.

As discussed in Section 3.3.2, the maximum gauge pressure that would develop in the package containment system in a period of one year under the heat conditions, considering partial pressure contributions from temperature change, water vapor pressure, and gas generation from radiolysis, is 15.3 psi (105 kPa) gauge. This is much lower than the 100 psig (690 kPa) gauge MNOP internal pressure load used to perform the CCV structural analysis for NCT.

2.6.1.2 Differential Thermal Expansion

Differential thermal expansion of the packaging components is evaluated considering possible interference resulting from a reduction in gap sizes. The differential thermal expansion evaluation includes radial and longitudinal differential thermal expansion between the CCV assembly and the OSV cavity and between the SIA and the CCV cavity. The results of the evaluation of differential thermal expansion show that the CCV expands freely within the OSV cavity and the SIA expands freely within the CCV cavity under NCT thermal loading.

2.6.1.2.1 Differential Thermal Expansion Between CCV and OSV

The package is designed with sufficient clearances between the OSV cavity and the outside surfaces of the CCV to permit free thermal expansion of the CCV under NCT and HAC. [redacted] As shown in Chapter 3, the maximum temperature differential between the CCV and OSV for NCT results from the package configuration with fuel waste contents. The results show that the maximum temperatures of the CCV and OSV are 288°F (142°C) and 221°F (105°C), respectively.

The differential thermal expansion between the CCV and OSV is evaluated [redacted] conservatively assuming an upper-bound temperature of 300°F (149°C) for the CCV and a lower-bound temperature of 200°F (93°C) for the OSV. The results show that differential thermal expansion of the between the CCV and OSV reduces the nominal axial and radial clearances to [redacted] respectively. Therefore, the CCV will expand freely within the OSV cavity under NCT heat.

2.6.1.2.2 Differential Thermal Expansion Between SIA and CCV

The package is designed with sufficient clearances between the CCV cavity and the outside surfaces of the SIA to permit free thermal expansion of the SIA under NCT and HAC. [redacted] As shown in Chapter 3, the maximum temperature of the SIA (conservatively taken as the maximum average content and fill gas temperature) results

from case HAC3 (i.e., volumetric heat source in a 110-gallon drum) with the maximum IFW decay heat load of 1500 watts. The results show that the maximum temperature of the SIA (contents) is 647°F (342°C).

The differential thermal expansion between the SIA and CCV is evaluated using [redacted] conservatively assuming an upper-bound temperature of 700°F (371°C) for the SIA and 70°F (21°C) for the CCV. The results show that differential thermal expansion of the between the SIA and CCV reduces the nominal axial and radial clearances to [redacted] respectively. Therefore, the SIA will expand freely within the CCV cavity under NCT heat.

2.6.1.3 Stress Calculations

The OPTIMUS®-H package is designed to withstand the effects of the hot environment (i.e., NCT heat) in accordance with 10 CFR 71.71(c)(1). Per Table 2.1-1, NCT heat consists of a 100°F (38°C) ambient temperature combined with maximum decay heat, maximum insolation, maximum internal pressure, and fabrication stresses. The OSV and SIA are not included in the NCT heat stress evaluation because they are designed in accordance with the allowable stress design criteria of ASME Subsection NF, which does not require evaluation of secondary stress, such as those stresses resulting from temperature-induced loading.

The results of the NCT heat stress analysis show that the maximum total (P_m+P_b+Q) stress intensity in the packaging due to NCT heat loading is 20.2 ksi (139 MPa), occurring at the center of the containment shell bottom plate (section C1 in Figure 2 1). This stress is due almost entirely to the internal pressure loading and not to the NCT heat temperature gradient. The maximum P_m+P_b+Q stress intensity in the packaging containment system for NCT is limited to $3.0S_m$. The minimum value of S_m for the packaging shell materials at a bounding design temperature of 300°F (149°C) is 20.0 ksi (138 MPa). Therefore, the allowable P_m+P_b+Q stress intensity for the containment system is 60.0 ksi (414 MPa) and the minimum design margin in the packaging containment system due to NCT heat loading is +1.97.

2.6.1.4 Comparison with Allowable Stresses

The results of the NCT heat structural evaluation demonstrate the packaging satisfies the applicable NCT allowable stress design criteria. NCT heat loading does not cause any permanent deformation of the package, nor does it substantially reduce the effectiveness of the packaging. Furthermore, since the evaluation shows that the containment seal is maintained under NCT heat loading, there would be no loss or dispersal of radioactive contents. Finally, the configuration of the package under NCT heat loading is bounded by that considered in the shielding evaluation. The NCT heat loading does not cause any significant increase in external surface radiation levels. Therefore, the package complies with the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a)(1) when subjected to the NCT heat test.

The structural evaluation of the package for reduced external pressure, increased external pressure, vibration normally incident to transport, and NCT free drop tests is discussed in the following sections. Each NCT test is evaluated in combination with the initial conditions expected to cause maximum package damage. The structural evaluation demonstrates that the package satisfies the applicable performance requirements specified in the regulations under all NCT tests. The evaluation of the packaging for cyclic service under NCT, which is presented in Section 2.1.2.4, demonstrates that the package satisfies the applicable fatigue design criteria of the ASME Code.

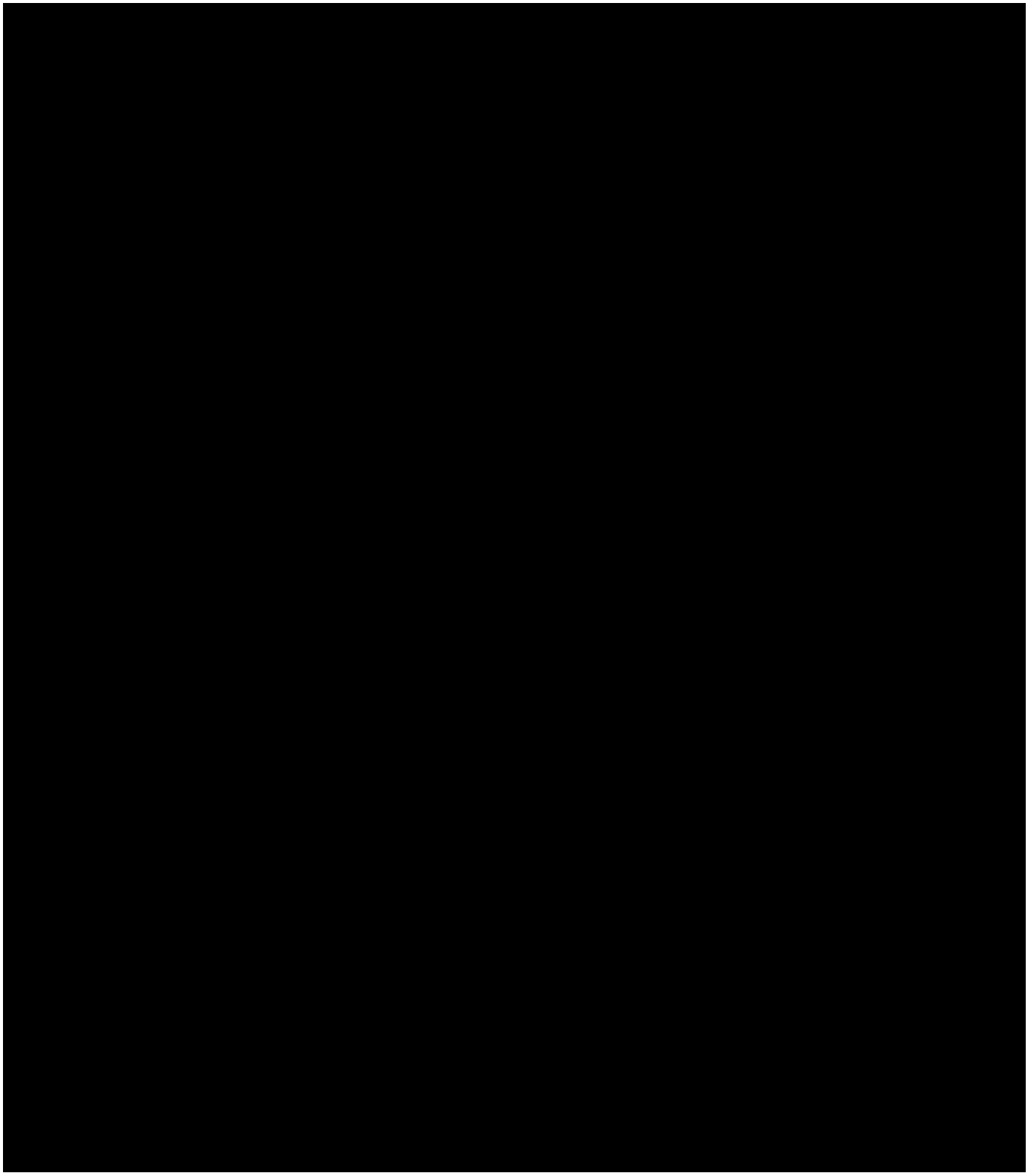


Figure 2.6-1 ½-Symmetry FEA Stress Analysis Model

Figure 2.6-2 Bounding NCT Heat Temperature Distribution

2.6.2 Cold

The package is designed to withstand the effects of a steady state ambient temperature of -40°F (-40°C) in still air and shade in accordance with 10 CFR 71.71(c)(2). Per Table 2.1-1, the NCT cold environment is evaluated in combination with zero insolation, zero decay heat, and zero internal pressure. Therefore, the NCT cold environment results in a uniform temperature of -40°F (-40°C) throughout the package.

The CCV assembly, which is made from austenitic stainless steel, is contained inside the cavity of the OSV assembly, which is made from ductile cast iron. Because the coefficient of thermal expansion of austenitic stainless steel is higher than that of ductile cast iron, reduced temperatures cause the stainless steel CCV to contract more than the OSV overpack. Therefore, the CCV will expand freely with the OSV cavity under NCT cold conditions.

The only thermal stresses in the packaging due to NCT cold are those resulting from differential thermal expansion of the closure bolts and lids, which are made of dissimilar materials. The stresses in the packaging closure bolts due to NCT cold loading are determined [redacted] as discussed in Section 2.12.5. As shown in Table 2.12-4, the maximum tensile force (F_a) in the CCV and OSV closure bolts for NCT cold are bounded by those due to NCT heat. Because the CCV closure bolts have a slightly lower coefficient of thermal expansion than the CCV lid, NCT cold results in a reduction of the CCV closure bolt stresses, but not enough to overcome the bolt preload. Therefore, the CCV closure seal will be maintained under NCT cold loading. Furthermore, it is concluded that the closure bolt stresses due to NCT cold are bounded by those resulting from other NCT load combinations.

The results of the NCT cold structural evaluation demonstrate that the packaging satisfies the applicable NCT allowable stress design criteria. NCT cold loading does not cause any permanent deformation of the packaging, nor does it substantially reduce the effectiveness of the packaging. Furthermore, since the evaluation shows that the containment seal is maintained under NCT cold loading, there would be no loss or dispersal of radioactive contents. Finally, the configuration of the package under NCT cold loading is bounded by that considered in the shielding evaluation. Therefore, NCT cold loading does not cause any significant increase in external surface radiation levels. The package thus complies with the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a)(1) when subjected to NCT cold conditions.

2.6.3 Reduced External Pressure

In accordance with 10 CFR 71.71(c)(3) the package is designed to withstand the effects of a reduced external pressure of 3.5 psi (25 kPa) absolute. Per Table 2.1-1, reduced external pressure loading is considered in combination with MNOP, NCT heat, and fabrication stresses. The OSV stresses are not included in the reduced external pressure evaluation because it is not a pressure-retaining component.

Under NCT heat conditions, MNOP does not exceed 100 psi (690 kPa) gauge. Therefore, the greatest pressure difference between the inside and outside of the containment system is 111.2 psi (725 kPa). The only significant fabrication stresses in the package are those resulting from closure bolt preload. Lower-bound bolt preloads are used to evaluate CCV seal integrity under reduced external pressure loading. However, the full range for bolt preload is considered for stress evaluation of the CCV closure bolts in accordance with NUREG/CR-6007 [2.28], as discussed below. Therefore, the following load combinations are considered for the evaluation of reduced external pressure loading:

(A) Reduced External Pressure + MNOP + Bolt Preload

(B) Reduced External Pressure + MNOP + Bolt Preload + NCT Heat

Thermally-induced stress intensities are classified as secondary in accordance with the ASME Code since they are self-limiting. Therefore, the stress intensities obtained from load combination (B) are compared to the stress limits for primary plus secondary (P_m+P_b+Q) stress intensity.

The maximum stress intensities in the CCV components are summarized in Table 2.6-1, along with the corresponding allowable stress intensities and minimum design margins. The results show that the maximum stress intensities in the CCV due to reduced external pressure loading are lower than the corresponding allowable stress intensities. The minimum design margin for reduced external pressure loading is +0.69 for primary membrane plus bending stress intensity (P_m+P_b) at the center of the CCV bottom plate (section C1 in Figure 2 1).

[redacted]

The stresses in the CCV closure bolts due to NCT reduced external pressure are determined [redacted] as discussed in Section 2.12.5. The OSV bolts are not evaluated for reduced external pressure loading because the OSV is not pressure retaining, and therefore, is not affected by reduced external pressure loading. NCT reduced external pressure loading is applied in combination with NCT heat temperature loading, maximum internal pressure, and maximum bolt preload. The maximum combined bolt stresses and corresponding stress ratios in the CCV bolts for NCT reduced external pressure (i.e., L.C. N2) are summarized in Table 2.12-6. The maximum stress ratio for the CCV closure bolts for NCT reduced external pressure is 0.98 from average tensile stress. The corresponding minimum margin of safety in the CCV closure bolts for NCT reduced external pressure, based on the stress ratio limit or 1.0, is +0.02.

The results of the NCT reduced external pressure structural evaluation demonstrate that the package containment system satisfies the applicable NCT allowable stress design criteria. Reduced external pressure loading does not cause any permanent deformation of the package, substantially reduce the effectiveness of the packaging, result in any loss or dispersal of radioactive contents, or cause any significant increase in external surface radiation levels. Therefore, the package complies with the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a)(1) when subjected to the NCT reduced external pressure test specified in 10 CFR 71.71(c)(3).

Table 2.6-1 Reduced External Pressure Stress Summary

2.6.4 Increased External Pressure

In accordance with 10 CFR 71.71(c)(4), the package is designed to withstand the effects of an increased external pressure of 20 psi (140 kPa) absolute. The OSV, which is not a pressure-retaining component, is not affected by increased external pressure. The SIA, contained inside the CCV cavity, is also not affected by increased external pressure. Furthermore, the effect of increased external pressure on the CCV is considered negligible. This conclusion is evident by comparison to the results of the evaluation of the deep-water immersion test discussed in Section 2.7.7. The magnitude of the external pressure load for deep-water immersion is 14.5 times greater than the reduced external pressure, whereas the ratio of HAC-to-NCT allowable stress limits is slightly greater than 2.

2.6.5 Vibration

In accordance with 10 CFR 71.71(c)(5), the package is subjected to vibration normally incident to transport. The package is transported in a vertical orientation. The package is supported by the bottom end of the lower impact limiter and tied down by either the four tiedown lugs or the two trunnions located on the OSV body. Based on testing performed in part by Sandi Laboratories [2.22], the peak vibration accelerations for transport are concluded to be much lower than those resulting from the NCT free drop evaluated in Section 2.6.7. Therefore, it is concluded that the packaging stresses due to NCT vibration satisfy the allowable stress design criteria for NCT. The primary concern for NCT vibration is fatigue failure of the packaging, which is discussed in Section 2.1.2.4.

The stresses in the CCV and OSV closure bolts due to NCT vibration are determined [redacted], as discussed in Section 2.12.5. Two separate load combinations are evaluated for NCT vibration loading. The first (L.C. N3) combines NCT vibration with NCT heat temperature loading, MNOP, and maximum bolt preload and the second (L.C. N4) combines NCT vibration with NCT cold temperature loading, MNOP, and minimum bolt preload. The maximum combined bolt stresses and corresponding stress ratios in the CCV and OSV bolts for the load combinations that include NCT vibration (i.e., L.C. N3 and N4) are summarized in Table 2.12-6. The maximum stress ratios for the CCV and OSV closure bolts for NCT vibration, both resulting from average tensile stress, are 0.96 and 0.23, respectively. The corresponding minimum margins of safety in the CCV and OSV closure bolts for NCT vibration, based on the stress ratio limit or 1.0, are +0.04 and +3.35, respectively.

Therefore, it is concluded that the packaging satisfies the applicable NCT allowable stress design criteria for NCT vibration. NCT vibration loading does not cause any permanent deformation of

the package, nor does it substantially reduce the effectiveness of the packaging. Finally, the configuration of the package under NCT vibration loading is bounded by that considered in the shielding evaluation. Therefore, NCT vibration loading does not cause any significant increase in external surface radiation levels. The package thus complies with the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a)(1) when subjected to the NCT vibration test specified in 10 CFR 71.71(c)(5).

2.6.6 Water Spray

In accordance with the requirements of 10 CFR 71.71(c)(6), the package must be subjected to a water spray that simulates exposure to rainfall of approximately 2 in/h (5 cm/h) for at least 1 hour. Quenching effects due to the water spray test will not significantly affect the package. The ends of the OSV assembly, and the CCV assembly inside the OSV assembly, are isolated from the quenching effects of the water spray by the upper and lower impact limiter assemblies, which insulate the OSV and CCV from sudden environmental changes. Furthermore, the thermal mass of the OSV is large enough to significantly slow the thermal response to sudden external temperature changes. Therefore, this condition is not significant in the structural design of the package and is not analyzed.

2.6.7 Free Drop

In accordance with 10 CFR 71.71(c)(7), the package, which weighs more than 22,000 pounds (10,000 kg) with the lightest payload, is subjected to a free drop through from 2 feet (0.6 m) onto a flat, essentially unyielding, horizontal surface, striking in a position for which maximum damage is expected. The package is evaluated for three different NCT free drop impact orientations, as shown in Figure 2.6-3. These include a top end drop, top corner drop, and side drop. The package accelerations for the NCT bottom end and bottom corner drops will be the same as those for the NCT top end and top corner drops because of symmetry. Therefore, the separate impact evaluations for the NCT bottom end and bottom corner drops are not performed. Furthermore, NCT oblique drops are not evaluated since they are expected to be bounded by the side drop acceleration loads because the OPTIMUS®-H package has a very small aspect ratio (i.e., height to diameter).

The dynamic response of the package to the NCT free drop test conditions is determined using [redacted] described in Section 2.12.2.2. In accordance with Regulatory Guide 7.8 [2.3], the worst-case initial conditions are considered for the NCT free drop test. These initial conditions include ambient temperatures that range from -20°F (-29°C) with zero decay heat and zero insolation (i.e., “cold” thermal condition) to an

ambient temperature of 100°F (38°C) with maximum decay heat and maximum insolation (i.e., "hot" thermal condition). Conservatively, a lower-bound ambient temperature of -40°F (-40°C) is used for the NCT free drop evaluation. The "cold" thermal condition is evaluated using the upper-bound dynamic crush strength properties of the impact limiter foam to determine the maximum loads imparted to the packaging, whereas the "hot" thermal condition is evaluated using the lower-bound dynamic crush strength properties of the impact limiter foam to determine the maximum damage to the packaging (i.e., impact limiter crush depth).

[redacted]

The drop analysis is used to predict the acceleration loading on the CCV, OSV, and contents for each NCT free drop impact orientation. In addition, this analysis demonstrates the structural adequacy of the impact limiter assembly for the NCT free drop tests. The maximum loads and stresses in the impact limiter attachments are shown to satisfy the applicable allowable stress design criteria. Furthermore, the maximum crush depth of the impact limiter polyurethane foam due to each NCT free drop is much less than the allowable crush depth.

A detailed stress analysis of the CCV and OSV is performed [redacted] Bounding equivalent-static acceleration design loads are applied to the finite element model for each NCT free drop orientation. The bounding equivalent-static acceleration design loads are determined by multiplying the cask peak rigid-body accelerations determined in Section 2.6.7.1 by dynamic load factors (DLFs) to

[redacted]

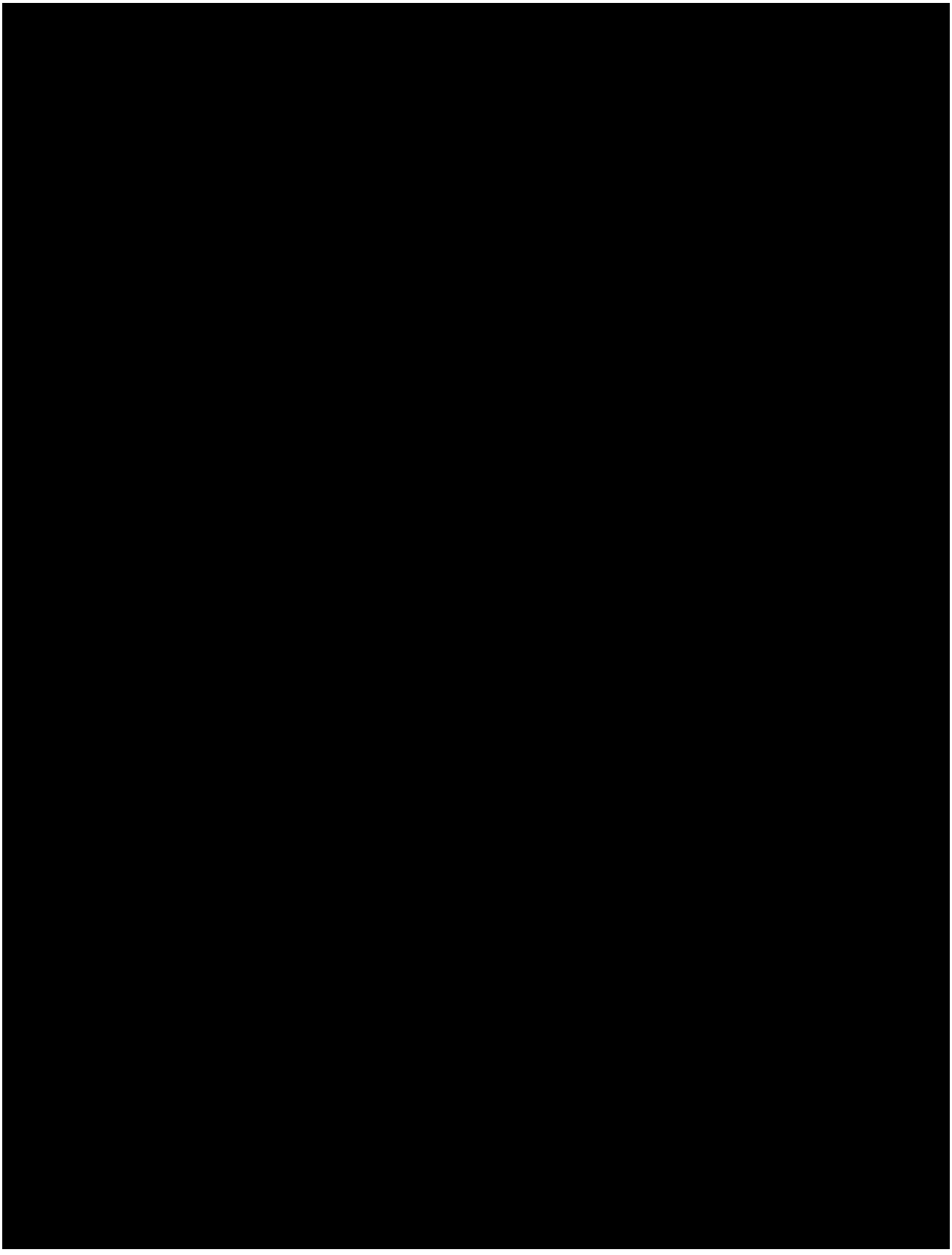
account for possible dynamic amplification within the cask. The maximum stresses in the CCV and OSV due to each NCT free drop are calculated and shown to satisfy the applicable allowable stress design criteria of Subsections NB [2.5] and NF [2.7] of the ASME Code, respectively. In addition, the compressive stresses in the CCV shells due to each NCT free drop are evaluated in accordance with ASME Code Case N-284-1 [2.8] and shown to satisfy the applicable buckling design criteria. The packaging NCT free drop stress analysis and buckling analysis are discussed further in Sections 2.6.7.2 and 2.6.7.3, respectively.

The stress analysis of the SIA is performed using classical hand calculations. The maximum stresses at the critical sections of the SIA due to each NCT free drop are calculated and shown to satisfy the applicable allowable stress design criteria of Subsections NF [2.7] of the ASME Code.

The results of the NCT free drop structural evaluation demonstrate that the packaging satisfies the applicable NCT allowable stress design criteria. NCT free drop loading does not cause any significant permanent deformation of the packaging, except for the impact limiter, nor does it substantially reduce the effectiveness of the packaging. Furthermore, since the evaluation shows that the containment seal is maintained under NCT free drop loading, there would be no loss or dispersal of radioactive contents. Finally, the configuration of the package under NCT free drop loading is bounded by that considered in the shielding evaluation. Therefore, NCT free drop loading does not cause any significant increase in external surface radiation levels. Thus, the package complies with the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a)(1) when subjected to the NCT free drop test.

2.6.7.1 Drop Loads Evaluation

The drop loads evaluation of the package for the NCT free drop test is performed using the



[redacted].

The maximum impact limiter deformation and peak rigid-body accelerations resulting from each NCT free drop orientation are summarized in Table 2.6-3. The results show that the maximum impact limiter crush depth for each NCT free drop orientation results from the hot/heavy case, and the maximum overall crush depth of 2.7 inches (7 cm) results from the NCT corner drop (Case NC1). The impact limiter deformation resulting from the NCT top end drop (Case NE2), NCT top corner drop (Case NC1), and NCT side drop (Case NS2) are shown in Figure 2.6-8, Figure 2.6-10, and Figure 2.6-12, respectively.

The results of the NCT free drop evaluation show the highest package peak rigid-body accelerations for all orientations result from the cold/light cases. However, due to the large difference between the heavy and light CCV content weights, the largest forces on the CCV from the contents result from the cold/heavy cases for all NCT free drop orientations. The rigid-body acceleration time-history curves for the NCT cold/light top end drop (Case NE1), NCT cold/light top corner drop (Case NC1), and NCT cold/light side drop (Case NS1) are shown in Figure 2.6-9, Figure 2.6-11, and Figure 2.6-13, respectively.

The results of the NCT free drop evaluation summarized in Table 2.6-3 also show the highest tensile forces in the ILS attachment bolt result from the NCT side drop, whereas the highest tensile forces in the OSV and CCV closure bolts results from the NCT corner drop. The maximum tensile forces in the OSV and CCV lid closure bolts are evaluated in combination with the bolt loads due to MNOP, NCT heat, and fabrication (i.e., bolt preload) in accordance with NUREG/CR-6007, as discussed in Section 2.6.7.2. The highest tensile force in the impact limiter attachments is 12.9 kip (57 kN). The ultimate tensile load of the [redacted] turnbuckle jaw-end fitting is 5 times the working load limit, or 50.0 kip (222 kN). For NCT, the maximum tensile load in the impact limiter attachments is limited to one-half of the ultimate tensile load per Table 2.1-4, or 25 kip (111 kN). Thus, the impact limiter attachments satisfy the applicable allowable stress design criteria for the NCT free drop test.

The impact limiter damage resulting from the NCT free drop is minimal and will not affect the ability of the package to withstand the HAC tests required by 10 CFR 71.73. The most noticeable impact limiter damage for all NCT free drop results from the corner drop, as shown in Figure

2.6-10. The extent of damage to the impact limiter resulting from the NCT corner drop is limited to the impacted corner, which is permanently deformed inward by 2.7 inches (7 cm). Since this deformation does not significantly reduce the overall amount of energy-absorption capability available for the HAC corner drop, this damage does not affect the ability of the package to withstand the HAC tests required by 10 CFR 71.73.

2.6.7.2 Stress Evaluation

2.6.7.2.1 CCV and OSV

The stresses in the OSV and CCV assemblies due to NCT free drop loading are determined [redacted] Equivalent-static linear-elastic analyses are performed for those NCT top end and side drop orientations, which are expected to cause maximum damage to the package. The stresses in the packaging due to the NCT top corner drop are bounded by those due to the NCT end and side drop orientations. This conclusion is based on the comparison of the results of the NCT drop analysis summarized in Table 2.6-3, which show that the NCT top corner drop acceleration load is less than 1/3rd of the NCT end and side drop acceleration loads.

The equivalent static acceleration loads for each NCT free drop orientation are equal to the peak rigid body accelerations of the package multiplied by a DLF that accounts for possible dynamic amplification within the packaging. As discussed in Section 2.12.3, an upper bound DLF of 1.13 is conservatively applied to all NCT free drop rigid body accelerations. Table 2.6-3 provides a summary of the equivalent-static acceleration loads used for the structural evaluation of each NCT free drop orientation.

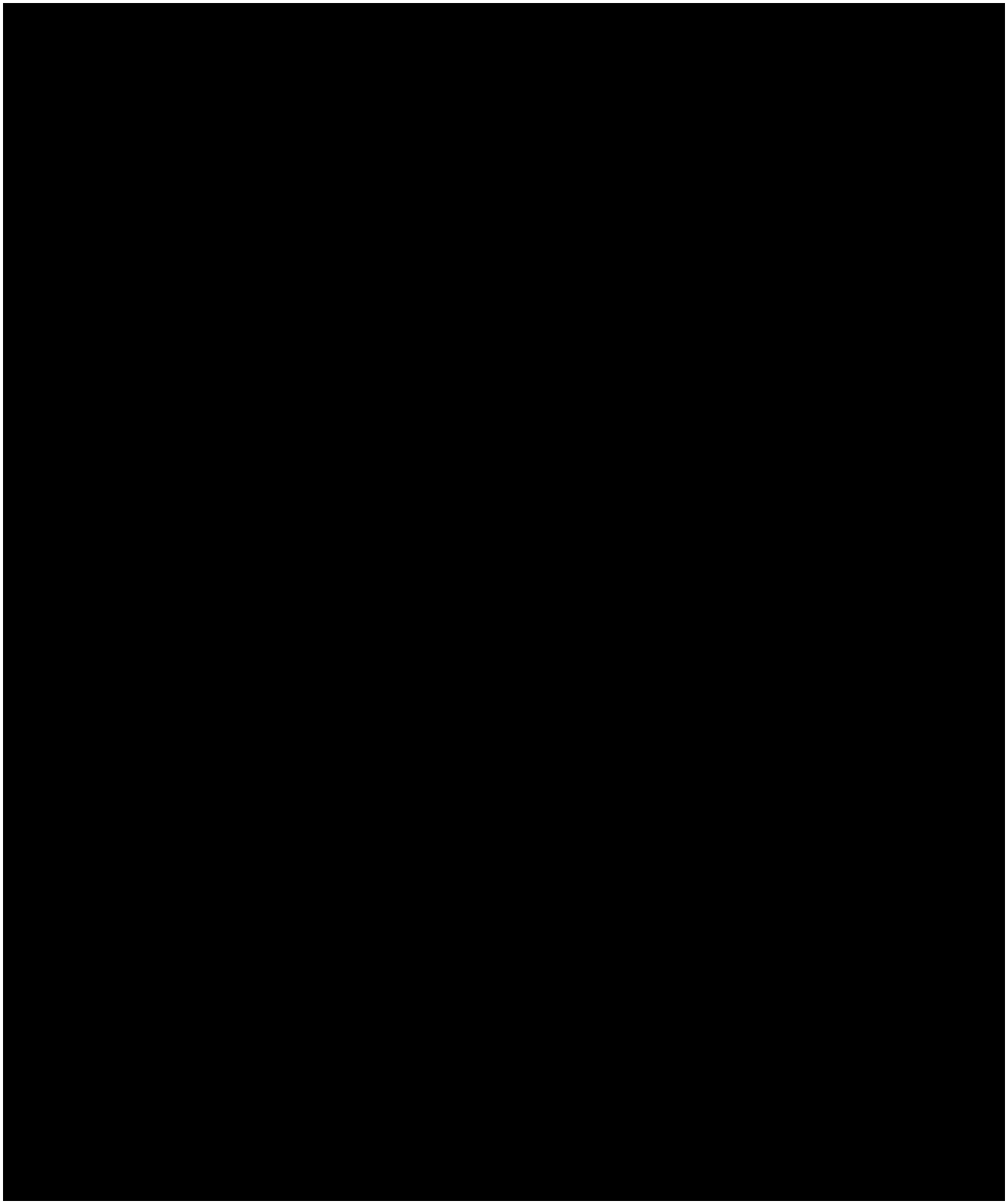
In accordance with Regulatory Guide 7.8 [2.3], NCT free drop loads are evaluated in combination with MNOP, NCT heat, and fabrication stresses. The only significant fabrication stresses in the package are those resulting from closure bolt preload. Lower-bound bolt preloads are used to evaluate CCV seal integrity under NCT free drop loading. However, the full range for bolt preload is considered for stress evaluation of the CCV closure bolts in accordance with NUREG/CR-6007 [2.28], as discussed below. Therefore, the following load combinations are considered for each NCT free drop load orientation evaluated:

(A) NCT Free Drop + Bolt Preload + MNOP

(B) NCT Free Drop + Bolt Preload + Max. Internal Pressure + NCT Heat

Thermally-induced stress intensities are classified as secondary in accordance with the ASME Code since they are self-limiting. Therefore, the stress intensities obtained from load

combination (B) are compared to the stress limits for primary plus secondary (P_m+P_b+Q) stress intensity.



[redacted] The maximum stress intensities in the CCV and OSV resulting from the NCT end and side drop orientations are summarized in Table 2.6-4 and Table 2.6-5, respectively, along with the location of the maximum stress intensity, the corresponding allowable stress intensity, and the resulting minimum design margin. The results show that the stresses due to the NCT top end drop are generally lower than those due to the NCT side drop. The minimum design margin is +0.05 for primary membrane plus bending (P_m+P_b) stress intensity in the CCV shell (at stress section C5) due to the NCT side drop. Therefore, the packaging satisfies the applicable allowable stress design criteria for the NCT free drop.

[redacted]

The stresses in the CCV and OSV closure bolts due to NCT free drop are determined [redacted], as discussed in Section 2.12.5. Two separate load combinations are evaluated for NCT free drop loading. The first (L.C. N5) combines NCT free drop with NCT heat temperature loading, MNOP, and maximum bolt preload and the second (L.C. N6) combines NCT free drop with NCT cold temperature loading, MNOP, and minimum bolt preload. The maximum combined bolt stresses and corresponding stress ratios in the CCV and OSV bolts for the load combinations that include NCT free drop (i.e., L.C. N5 and N6) are summarized in Table 2.12-6. The maximum stress ratios for the CCV and OSV closure bolts for NCT free drop, both resulting from average tensile stress, are 0.96 and 0.23, respectively. The corresponding minimum margins of safety in the CCV and OSV closure bolts for NCT free drop, based on the stress ratio limit or 1.0, are +0.04 and +3.35, respectively.

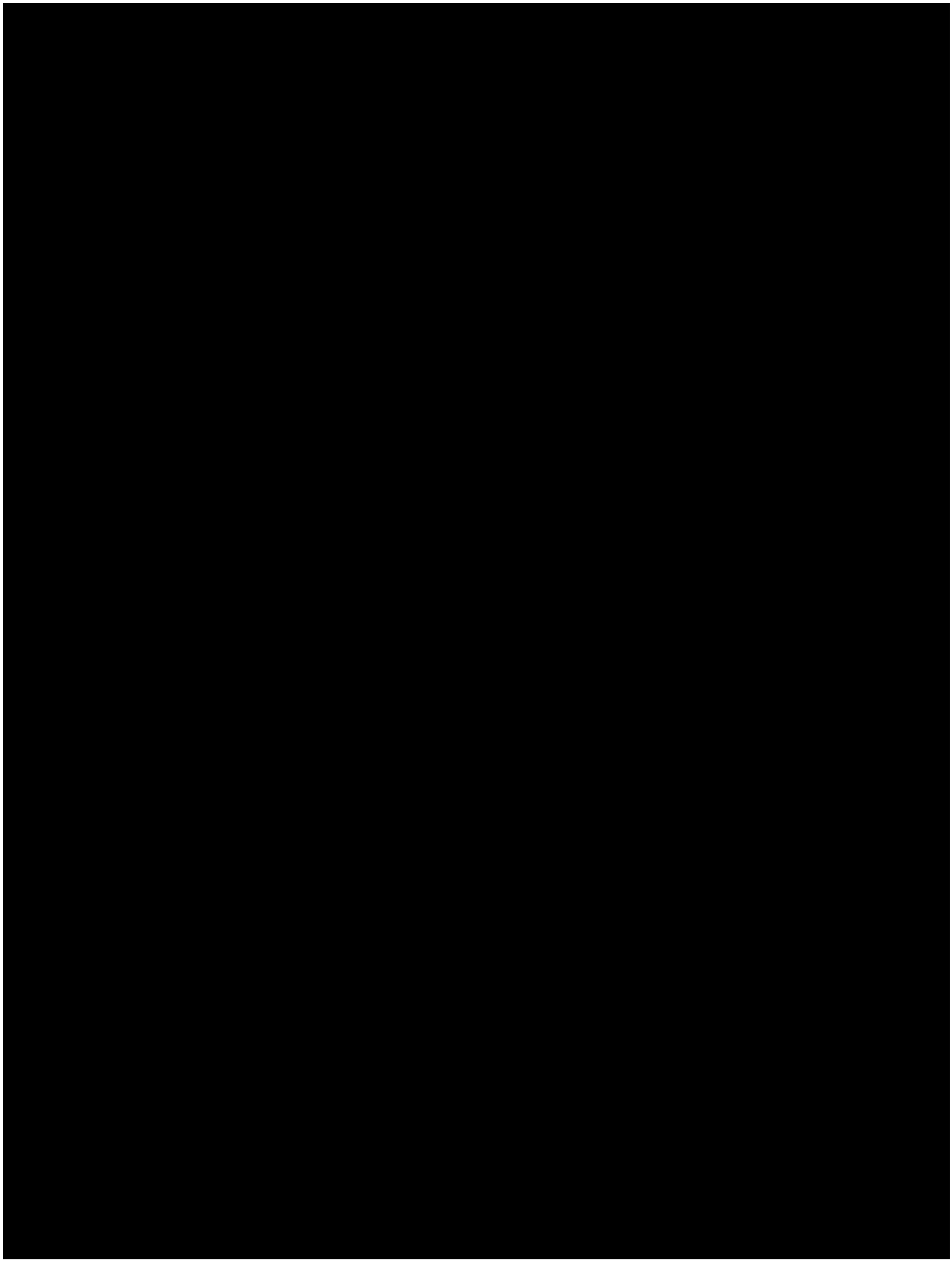
2.6.7.2.2 Shield Inserts

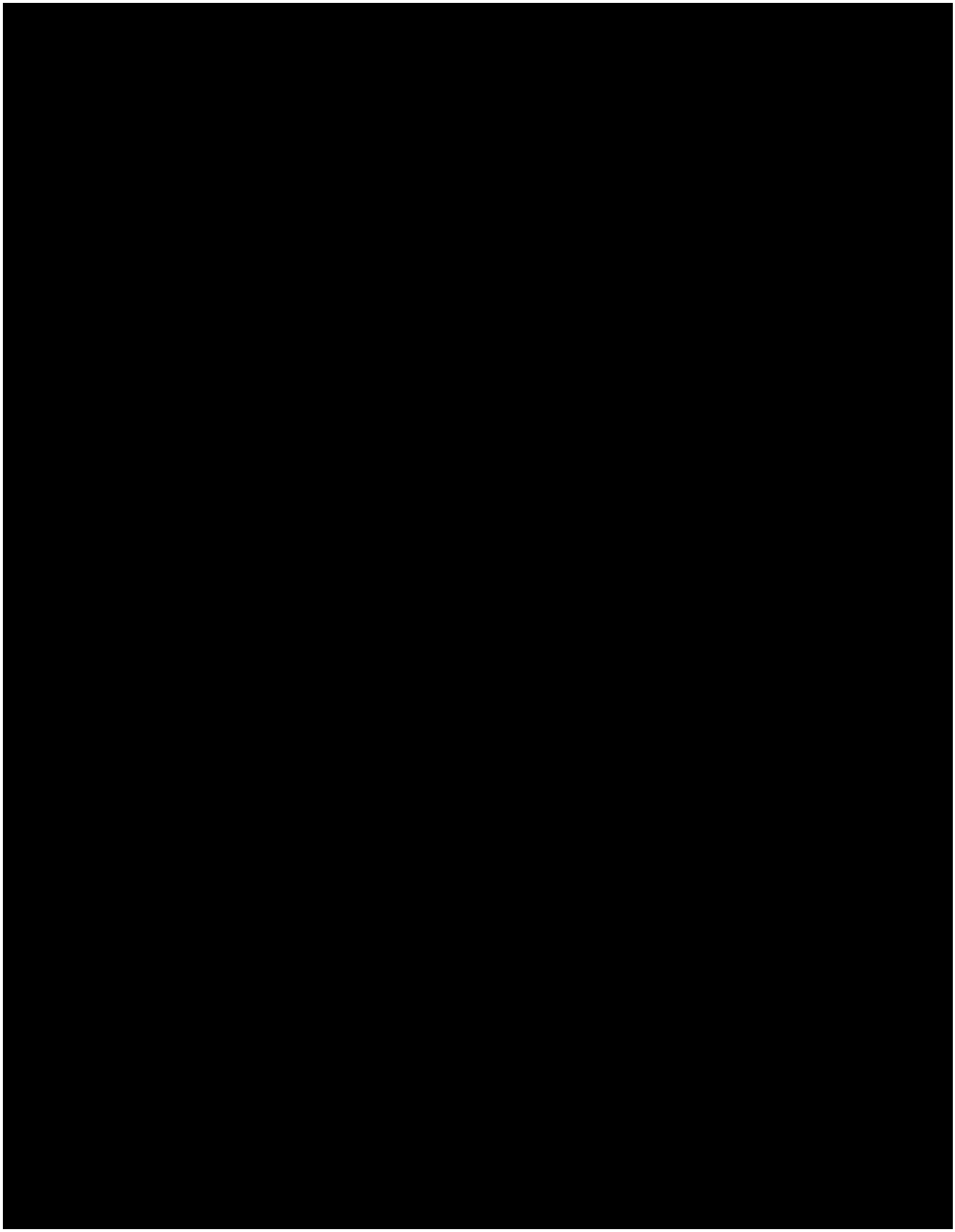
The stresses in the [redacted] SIA due to NCT free drop loading are determined using [redacted]. Stresses are calculated for NCT top end, bottom end, and side drop orientations. The stresses in the SIAs due to the NCT top corner drop are bounded by those due to the NCT end and side drop orientations.

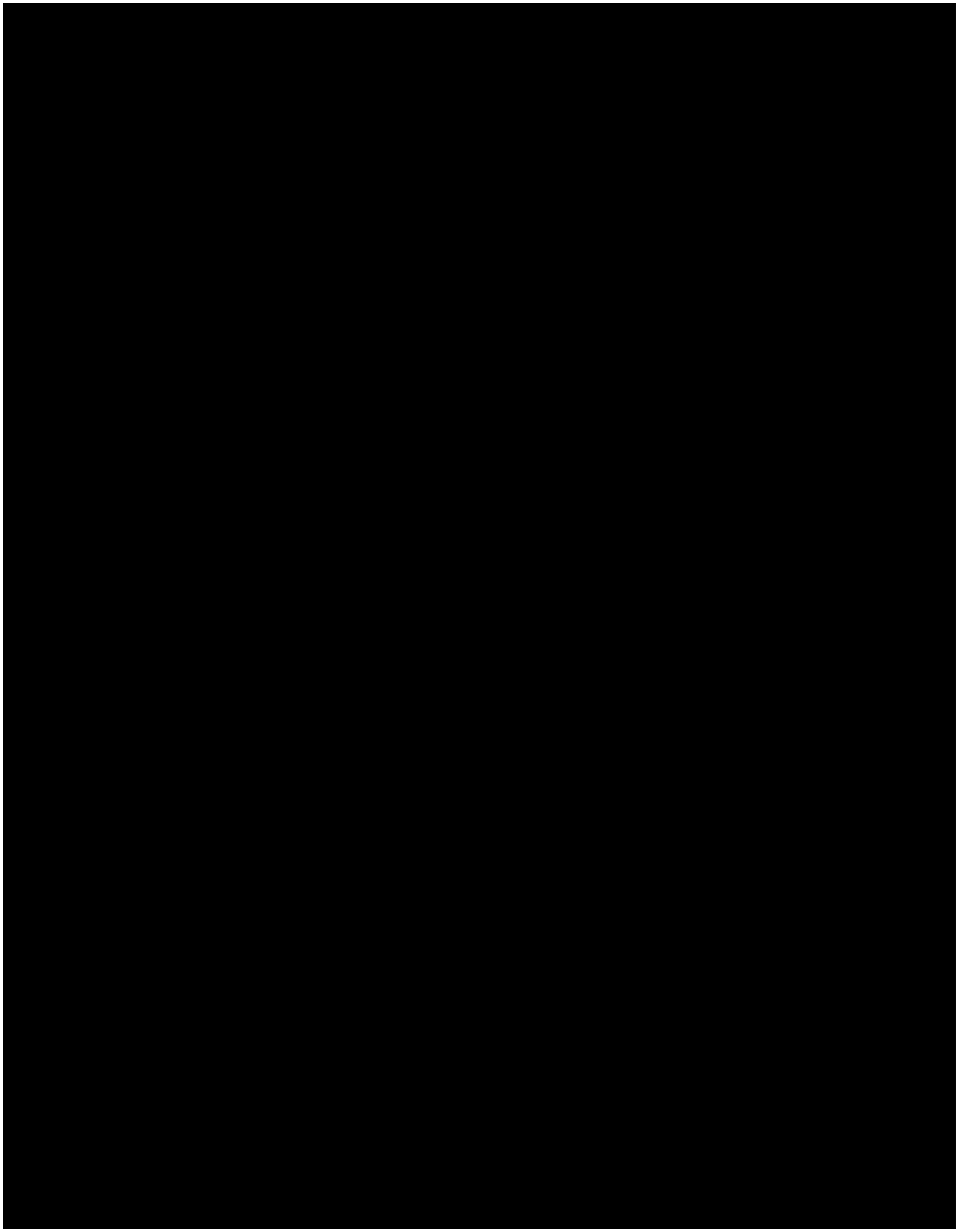
This conclusion is based on the comparison of the results of the NCT drop analysis summarized in Table 2.6-3, which show that the NCT top corner drop acceleration load is less than 1/3rd of the NCT end and side drop acceleration loads.

In accordance with Regulatory Guide 7.8 [2.3], NCT free drop loads are combined with MNOP, NCT heat, and fabrication stresses. MNOP does not cause any stresses in the SIA because it is not pressure-retaining. In addition, the shield inserts are designed in accordance with ASME Subsection NF, which does not require evaluation of thermal stresses. Finally, no significant fabrication stresses are expected in the SIA. Therefore, stresses in the SIA due to the NCT free drop need not combined be with any other stresses.

Top End Drop:







[redacted]

2.6.7.3 Buckling Evaluation

2.6.7.3.1 CCV

Buckling evaluations of the CCV shell are performed for the NCT free drop test in accordance with the requirements of [redacted] Bounding stresses in the CCV shell are determined for combined NCT free drop, NCT heat, and NCT increased external pressure loads, conservatively neglecting internal pressure because it results in tensile stresses in the CCV shell that increase the margin of safety for buckling. As discussed in Section 2.1.2.3, elastic and inelastic buckling interaction ratios are calculated based on the NCT allowable buckling stresses shown in Table 2.1-7, which include a factor of safety of 2.0. The maximum interaction ratios must not exceed 1.0.

As shown in Table 2.6-3, the cold/light NCT end drop (Case NE1) results in a significantly higher peak rigid-body acceleration (146*g*) than all other NCT free drop impact orientations. As discussed in Section 2.12.3, a maximum DLF of 1.13 is applied to the peak rigid-body acceleration, resulting in an equivalent static acceleration load of 165*g* for the cold/light NCT end drop.

[redacted]

The CCV shell stresses due to the NCT bottom end drop are combined with the stresses at the mid-length of the CCV shell (i.e., Section C7 in Figure 2.1-1) resulting from NCT increased external pressure and NCT heat. For increased external pressure loading the internal pressure is conservatively assumed to be zero, resulting in a net external pressure load of 5.3 psig. The resulting axial compressive stress, hoop compressive stress, and shear stress at the mid-length of the CCV shell are [redacted] to be 44 psi (0 MPa), 89 psi (1 MPa), and 23 psi (0 MPa), respectively. The axial compressive stress, hoop compressive stress, and shear

stress at the mid-length of the CCV shell [redacted] for NCT heat are 2.1 ksi (14 MPa), 0.1 ksi (1 MPa), and 1.0 ksi (7 MPa), respectively. The maximum combined stresses used for the CCV shell buckling analysis are summarized in Table 2.6-6.

The allowable stresses and interaction ratios for elastic and inelastic buckling are summarized in Table 2.6-7. The highest buckling interaction ratio in the CCV shell for the NCT free drop, including both elastic and inelastic buckling, is 0.53 for inelastic buckling due to axial compression plus shear, which is less than the limit of 1.0. Therefore, the CCV shell satisfies the buckling design criteria [redacted] for the NCT free drop.

2.6.7.3.2 Shield Inserts

[redacted] buckling analyses of the [redacted]h SIA for a bounding NCT bottom end drop load of 165g are performed [redacted] The results show that the eigenvalue (i.e., the factor of safety) for the lowest buckling modes of the [redacted] SIA are 12.4 and 5.0, respectively. Per Table NF-3221.2-1 of Subsection NF of the ASME Code [1], for normal conditions (i.e., Service Level A) the stress is limited to ½ of the critical buckling stress. Stated differently, the minimum factor of safety required against buckling is 2. Therefore, the minimum margins of safety against buckling of the [redacted] SIAs for the NCT bottom end drop is +1.50. These analyses demonstrate that the [redacted] SIA both satisfy the buckling design criteria for the NCT bottom end drop.

Table 2.6-2 Summary of NCT Free Drop Cases Evaluated

[redacted]

Table 2.6-3 NCT Free Drop Impact Analysis Results

[redacted]

Table 2.6-4 NCT Top End Drop Stress Summary

Table 2.6-5 NCT Side Drop Stress Summary

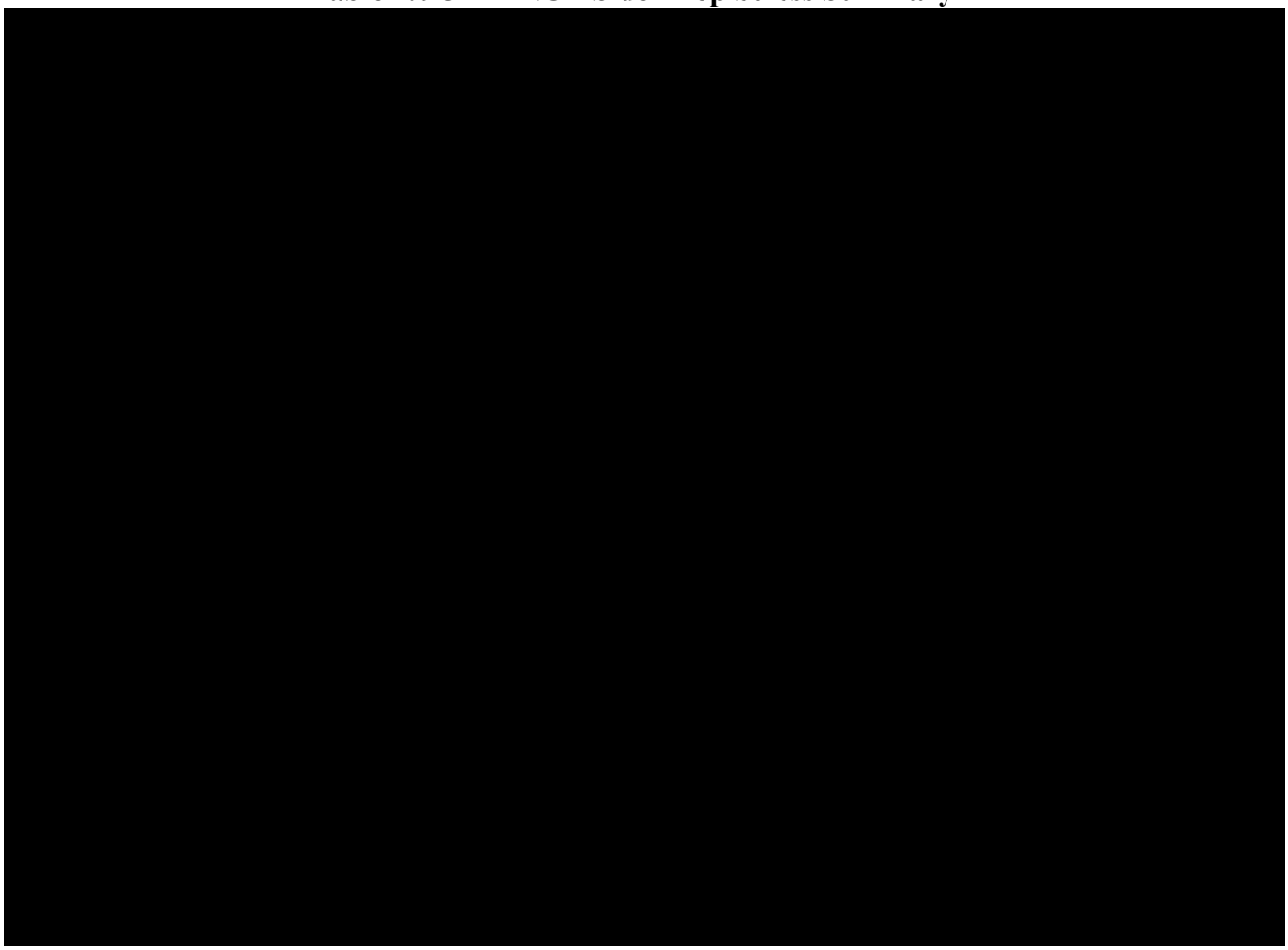


Table 2.6-6 CCV Shell NCT Free Drop Buckling Evaluation Stress Summary

[redacted]

Table 2.6-7 CCV Shell Buckling Evaluation Results for NCT Free Drop

[redacted]

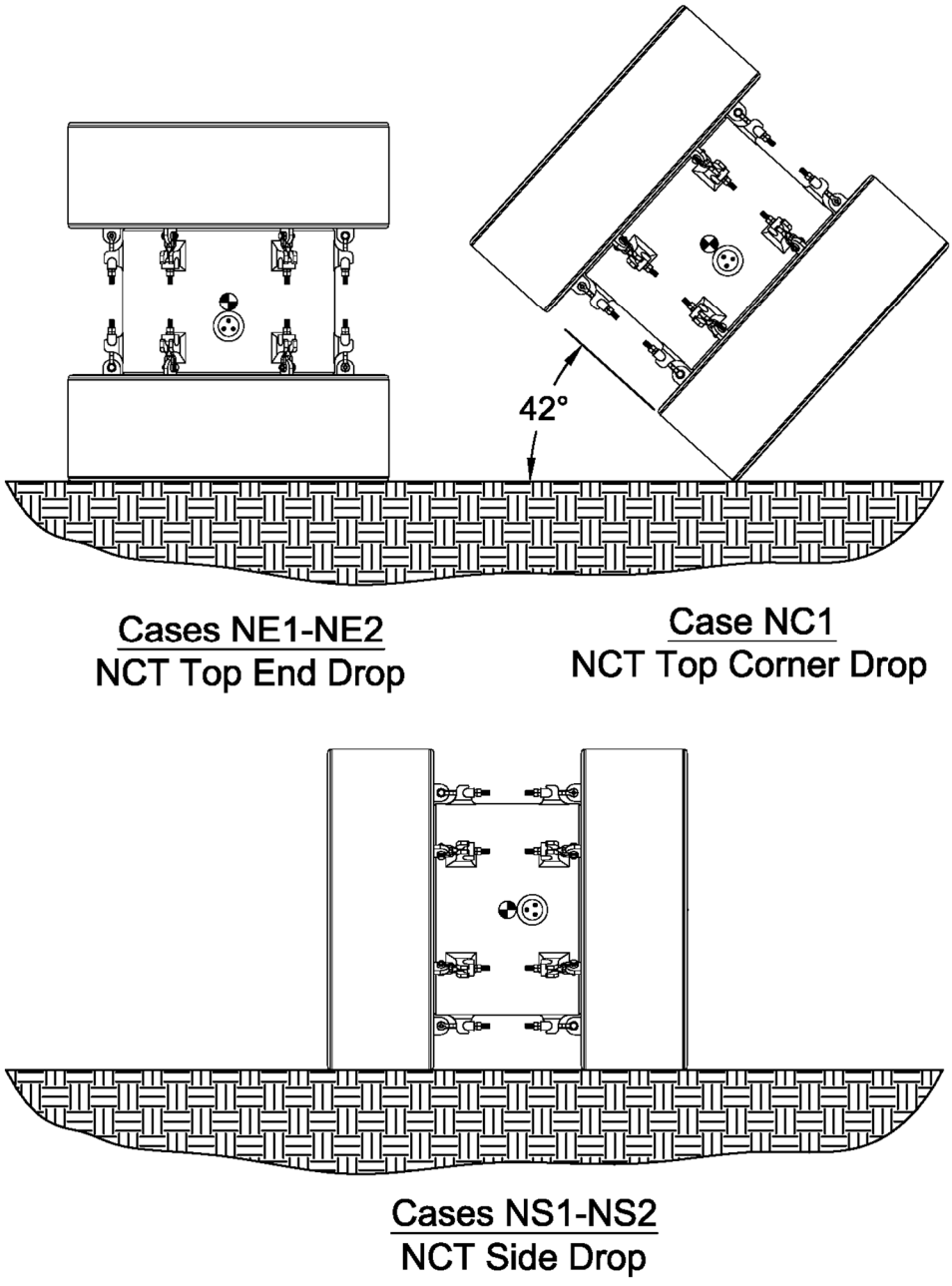


Figure 2.6-3 NCT 2-Foot (0.6 m) Free Drop Impact Orientations

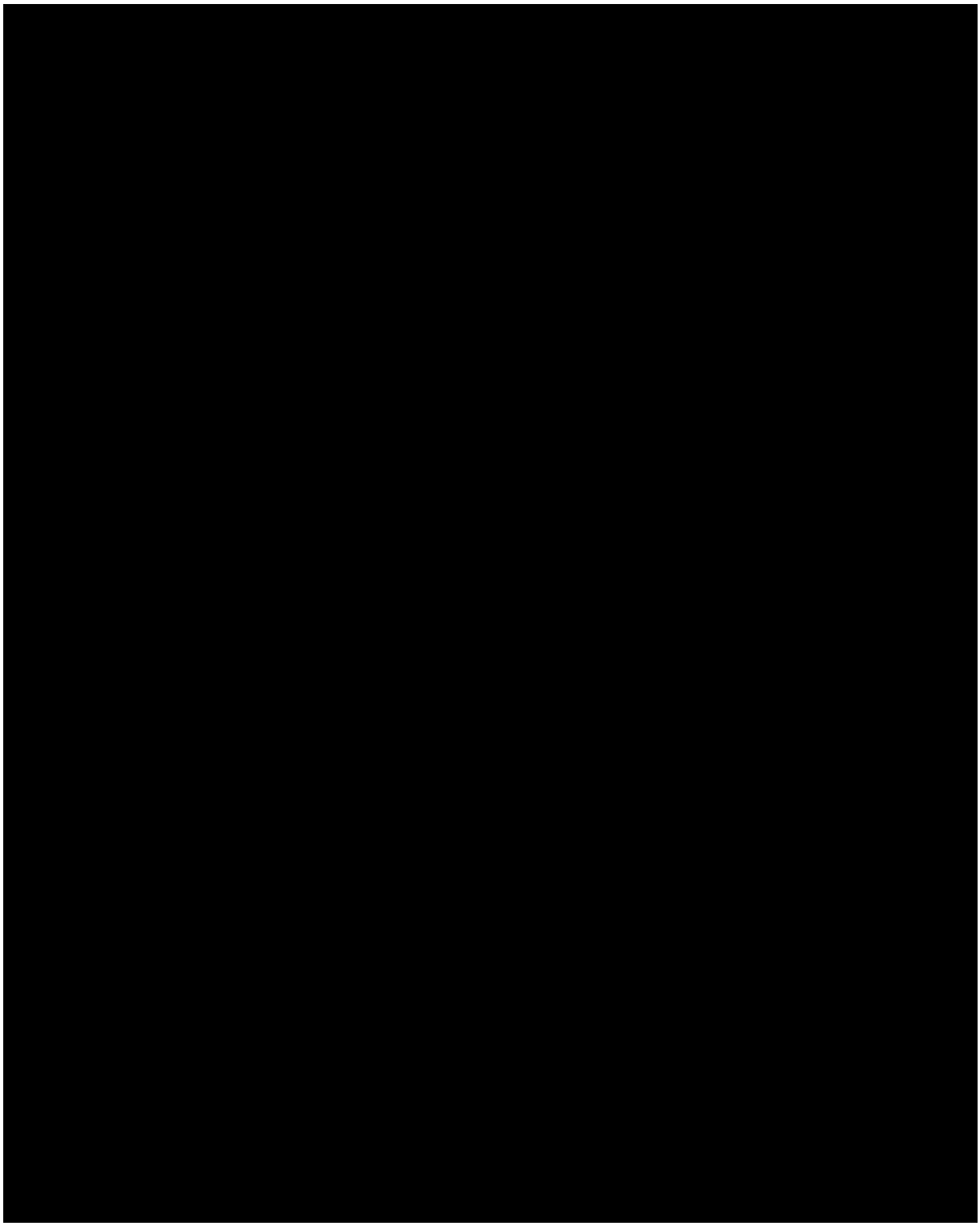


Figure 2.6-4 Drop Analysis ½-Symmetry Model – Isometric View

Figure 2.6-5 Drop Analysis [redacted] – Impact Limiter Detail

Figure 2.6-6 Drop Analysis [redacted] – OSV Closure Detail

Figure 2.6-7 Drop Analysis – CCV Closure Detail

Figure 2.6-8 NCT [redacted] Top End Drop (Case NE2) Impact Limiter Deformation

Figure 2.6-9 NCT [redacted]t Top End Drop (Case NE1) [redacted] Acceleration Time-History

Figure 2.6-10 NCT Top Corner Drop (Case NC1) Impact Limiter Deformation

Figure 2.6-11 NCT Top Corner Drop (Case NC1) Acceleration Time-History

**Figure 2.6-12 NCT [redacted] Side Drop (Case NS2)
Impact Limiter Deformation**

**Figure 2.6-13 NCT [redacted] Side Drop (Case NS1)
[redacted] Acceleration Time-History**

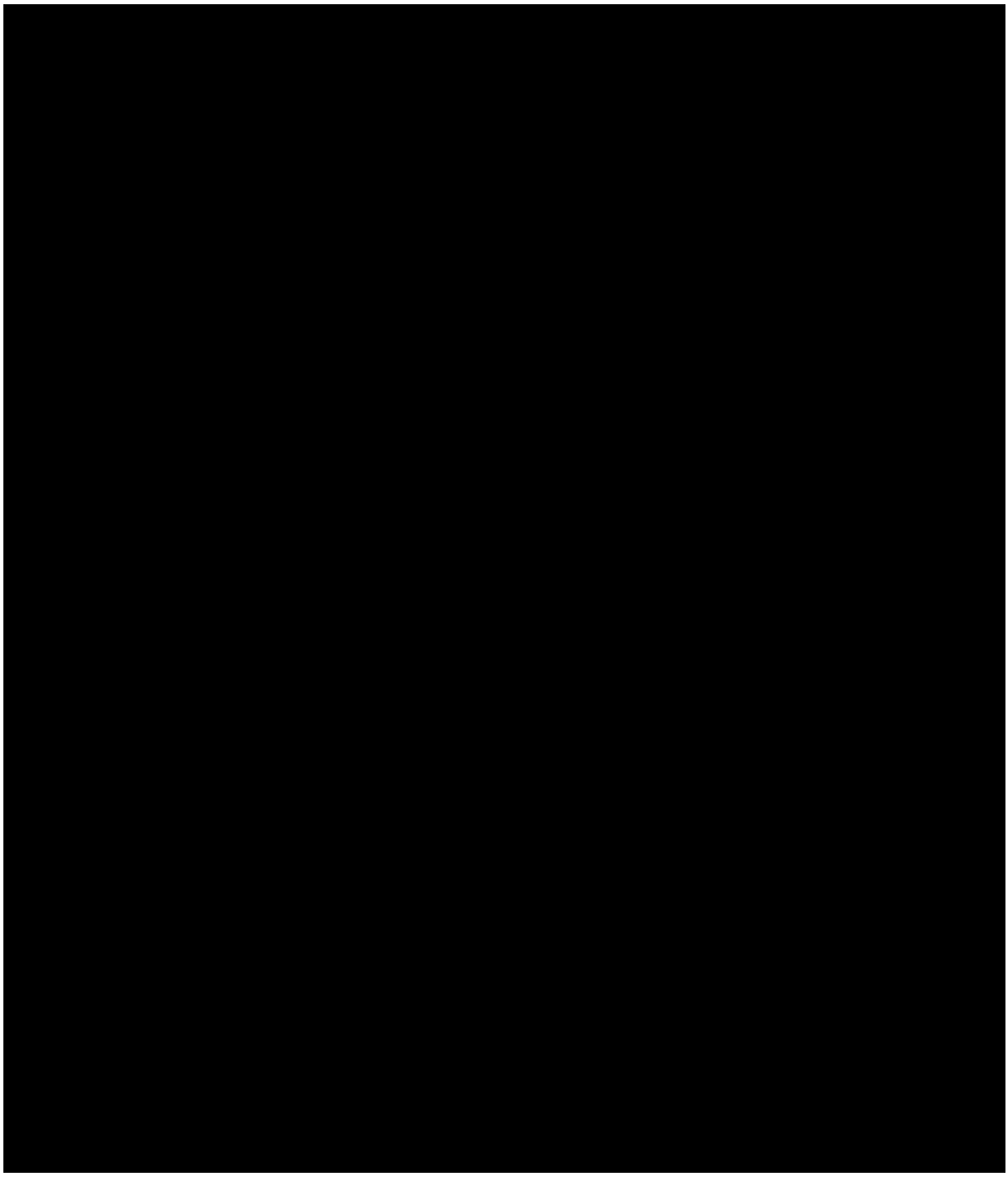


Figure 2.6-14

2.6.8 Corner Drop

In accordance with 10 CFR 71.71(c)(8), fiberboard, wood, or fissile material rectangular packages not exceeding 110 pounds (50 kg) and fiberboard, wood, or fissile material cylindrical packages not exceeding 220 pounds (100 kg) must be subjected to a free drop onto each corner of the package in succession, or in the case of a cylindrical package onto each quarter of each rim, from a height of 1 foot (0.3 m) onto a flat, essentially unyielding, horizontal surface. The package is not a fiberboard, wood, or fissile material package and it weighs more than 220 pounds (100 kg). Therefore, the corner drop test requirements of 10 CFR 71.71(c)(8) are not applicable to the package.

2.6.9 Compression

In accordance with 10 CFR 71.71(c)(9), packages must be subjected to a compressive (e.g., stacking) load, applied uniformly to the top and bottom of the package in a position in which the package would normally be transported. The compressive load is equal to the greater of the equivalent of 5 times the weight of the package, and 2 psi (13 kPa) multiplied by the vertically projected area of the package. The compression test requirements of 10 CFR 71.71(c)(9) do not apply because the package weighs more than 11,000 pounds (5,000 kg).

2.6.10 Penetration

In accordance with 10 CFR 71.71(c)(10), the package must be subjected to an impact of the hemispherical end of a vertical steel cylinder of 1.25 inch (3.2 cm) diameter and weighing 13 pounds (6 kg), dropped from a height of 40 inches (1 m) onto the exposed surface of the package that is expected to me most vulnerable to puncture. Per Regulatory Guide 7.8 [2.3], the penetration test is not structurally limiting for large packages without unprotected valves. The OPTIMUS®-H package is large and does not have any vulnerable locations on the package surface. Thus, the package need not be evaluated for NCT penetration.

THIS PAGE INTENTIONALLY LEFT BLANK

2.7 Hypothetical Accident Conditions

The package meets the standards specified in 10 CFR 71.51(a)(2) when subjected to the HAC tests specified in 10 CFR 71.73. In accordance with Regulatory Guide 7.6 [2.4], "design by analysis" is used for the structural evaluation of the package. The structural evaluation for HAC is based on sequential application of the HAC tests specified in 10 CFR 71.73(c) to determine the cumulative effect on the package, in accordance with 10 CFR 71.73(a). As discussed in Section 2.6, no significant package damage results from the NCT tests of 10 CFR 71.71. Thus, the evaluation of the package for the HAC test sequence is performed starting with an undamaged specimen. The package is evaluated for the most unfavorable initial conditions specified in 10 CFR 71.73(b). The HAC load combinations considered in the structural evaluation are developed in accordance with Regulatory Guide 7.8 [2.3] and summarized in Section 2.1.2.1.

The results of the structural evaluation show that the package satisfies the applicable allowable stress design criteria of the ASME Code when subjected to the HAC tests of 10 CFR 71.73. A summary of the cumulative package damage resulting from the HAC tests is provided in Section 2.7.8. The predicted package damage is considered in the package thermal, containment, and shielding HAC evaluations. The containment and shielding evaluations of the package show that the cumulative package damage resulting from the HAC test sequence results in no escape of other radioactive material exceeding a total amount of A_2 in one week and no external radiation dose rate exceeding 1 mrem/h (10 mSv/h) at 40 in (1 m) from the external surface of the package, in accordance with 10 CFR 71.51(a)(2).

2.7.1 Free Drop

In accordance with 10 CFR 71.73(c)(1), the package is subjected to a free drop of 30 feet (9 m) onto a flat, essentially unyielding, horizontal surface, striking in a position for which maximum damage is expected. The package is evaluated for a total of five (5) different HAC free drop orientations. These HAC free drop conditions are summarized in Table 2.7-1 and shown in Figure 2.7-1. They include upper-bound and lower-bound analyses for a top end drop, top corner drop, horizontal side drop, 5-degree bottom end oblique drop, and 10-degree bottom end oblique drop.

[redacted]

[redacted]. In accordance with the requirements of Regulatory Guide 7.8 [2.3], the worst case initial conditions are considered. For each HAC free drop impact orientation considered, upper bound and lower bound analyses are performed. The upper-bound analyses are performed using the impact limiter material upper-bound strength properties for the "cold" thermal condition temperature of -40°F (-40°C) with a lower bound content weight of 500 pounds (227 kg). [redacted] The lower-bound analyses are performed using the impact limiter material lower-bound strength properties for the "hot" thermal condition ambient temperature of 100°F (38°C), maximum decay heat, and insolation, combined with an upper-bound content weight of 7,300 pounds (3,311 kg). [redacted]

[redacted]

In accordance with Regulatory Guide 7.8 [2.3], HAC free drop loads are evaluated in combination with internal pressure (MNOP), and fabrication stresses. MNOP of 100 psig (690 kPa) gauge is evaluated in combination with the HAC free drop loads. The only significant fabrication and assembly stresses in the packaging are those resulting from closure bolt preload. Lower-bound closure preloads are combined with HAC free drop loading to evaluate seal integrity under HAC free drop loading. In addition, the closure bolt stress is evaluated in accordance with NUREG/CR-6007 [2.28] considering maximum and minimum bolt preloads in combination with HAC free drop.

The maximum stresses in the packaging due to each HAC free drop are calculated and shown to satisfy the applicable allowable stress design criteria of Subsection NF and Subsection NB of the ASME Code. In addition, the compressive stresses in the CCV shell due to HAC free drop loading are evaluated [redacted] and shown to satisfy the applicable buckling design criteria. Buckling of the CCV shell is evaluated for the HAC bottom end drop impact orientation only because the HAC end drop results in the highest overall acceleration loading and the bottom end impact results in the highest axial compressive stresses in the CCV shell. The results of the HAC bottom end drop buckling evaluation bound all other HAC free drop impact orientations. The packaging stress and buckling analyses for each HAC impact orientation are discussed further in the following sections.

The results of the HAC free drop structural evaluation demonstrate that the packaging satisfies the applicable HAC allowable stress design criteria. HAC free drop loading does not cause any significant permanent deformation of the packaging, except for the impact limiters, nor does it substantially reduce the effectiveness of the packaging. The evaluation shows that, under HAC free drop loading, the containment seal is maintained, and there is no loss or dispersal of radioactive contents. The damage to the impact limiters resulting from HAC free drop loading is considered in the HAC shielding evaluation, which demonstrates that the external dose rate limit requirements of 10 CFR 71.51(a)(2) are satisfied. Therefore, the package complies with the requirements of 10 CFR 71.51(a)(2) when subjected to the HAC free drop test of 10 CFR 71.73(c)(1).

Table 2.7-1 Summary of HAC Free Drop Cases Evaluated

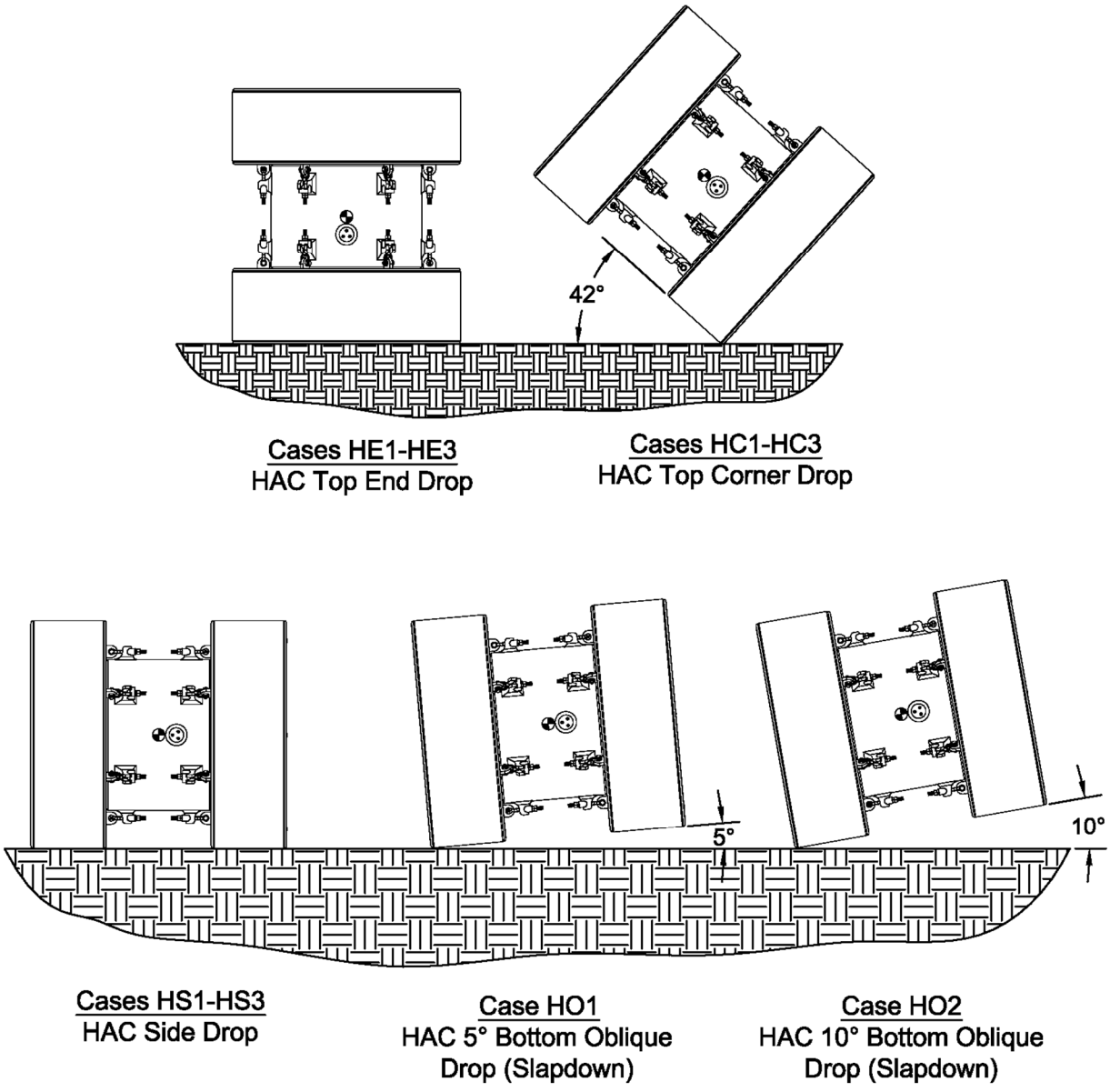


Figure 2.7-1 HAC Free Drop Impact Orientations

2.7.1.1 End Drop

The package is evaluated for a 30-foot (9 m) HAC end drop, occurring on either the top or bottom end of the package, considering the worst-case initial conditions in accordance with Regulatory Guide 7.8 [2.3]. The rigid-body dynamic response of the package to HAC top and bottom end free drops will be essentially identical due to axial symmetry. Furthermore, the stresses in the packaging due to the HAC top end drop are expected to be higher than those due to the HAC bottom end drop because the CCV and OSV lids support the combined inertial loading from their own masses and that of the contents under the HAC top end drop, whereas they only support the inertial loading from their own masses under the HAC bottom end drop. Therefore, the stress analysis of the packaging is only performed for the HAC top end free drop. However, the axial compressive stresses in the CCV shell are higher for the HAC bottom end drop because it supports the weight of the CCV bolt flange and lid in this orientation. Therefore, the buckling evaluation of the CCV shell is performed for the HAC bottom end drop orientation. The structural evaluation of the package for the HAC end drop test is described in the following sections.

2.7.1.1.1 Impact Limiter Evaluation

[redacted]

2.7.1.1.2 OSV and CCV Stress Evaluation

[redacted]

2.7.1.1.3 CCV Shell Buckling Evaluation

2.7.1.1.4 Shield Insert Stress Evaluation

Table 2.7-2 HAC End Drop Impact Limiter Analysis Results

[redacted]

Table 2.7-3 HAC Top End Drop Stress Summary

[redacted]

Table 2.7-4 CCV Shell HAC End Drop Buckling Evaluation Stress Summary

[redacted]

Table 2.7-5 CCV Shell Buckling Evaluation Results for HAC Bottom End Drop

[redacted]

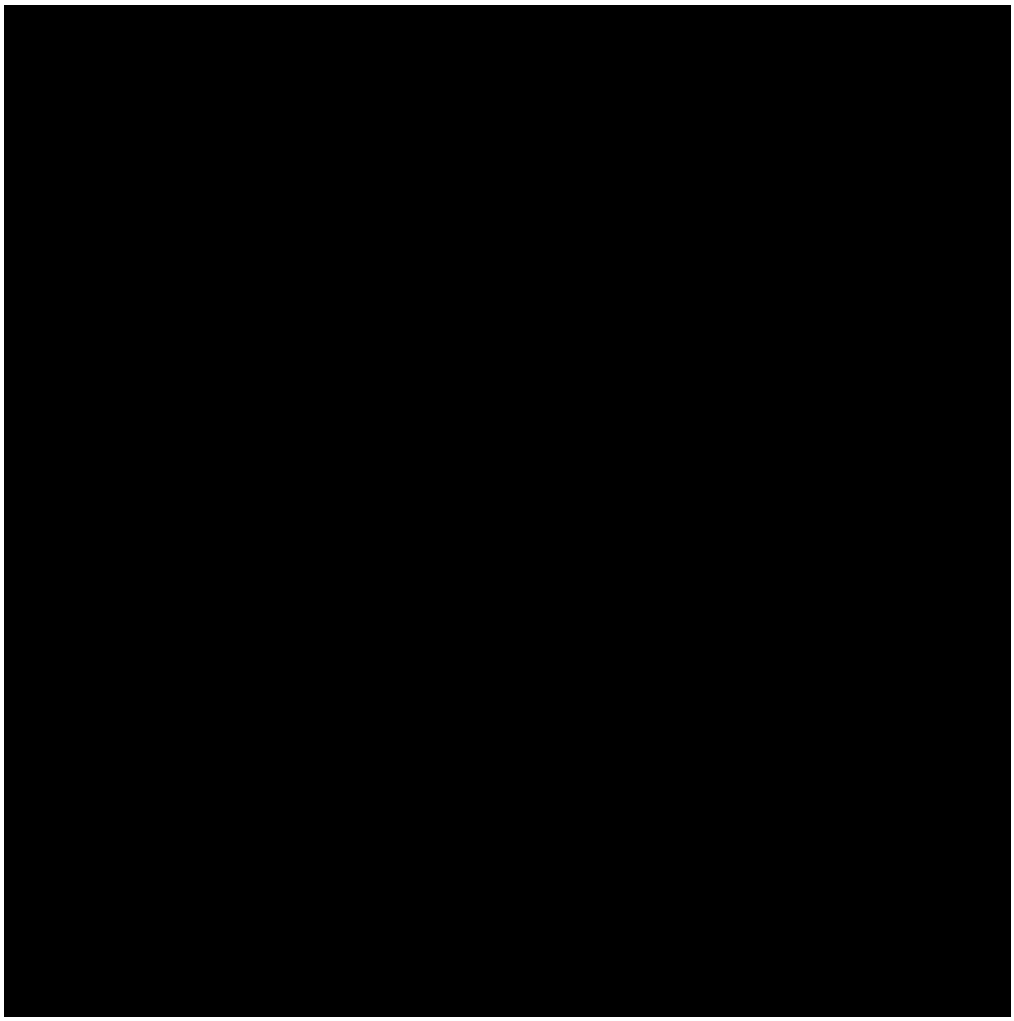


Figure 2.7-2 HAC [redacted] Top End Drop (Case HE2) Impact Limiter Deformation

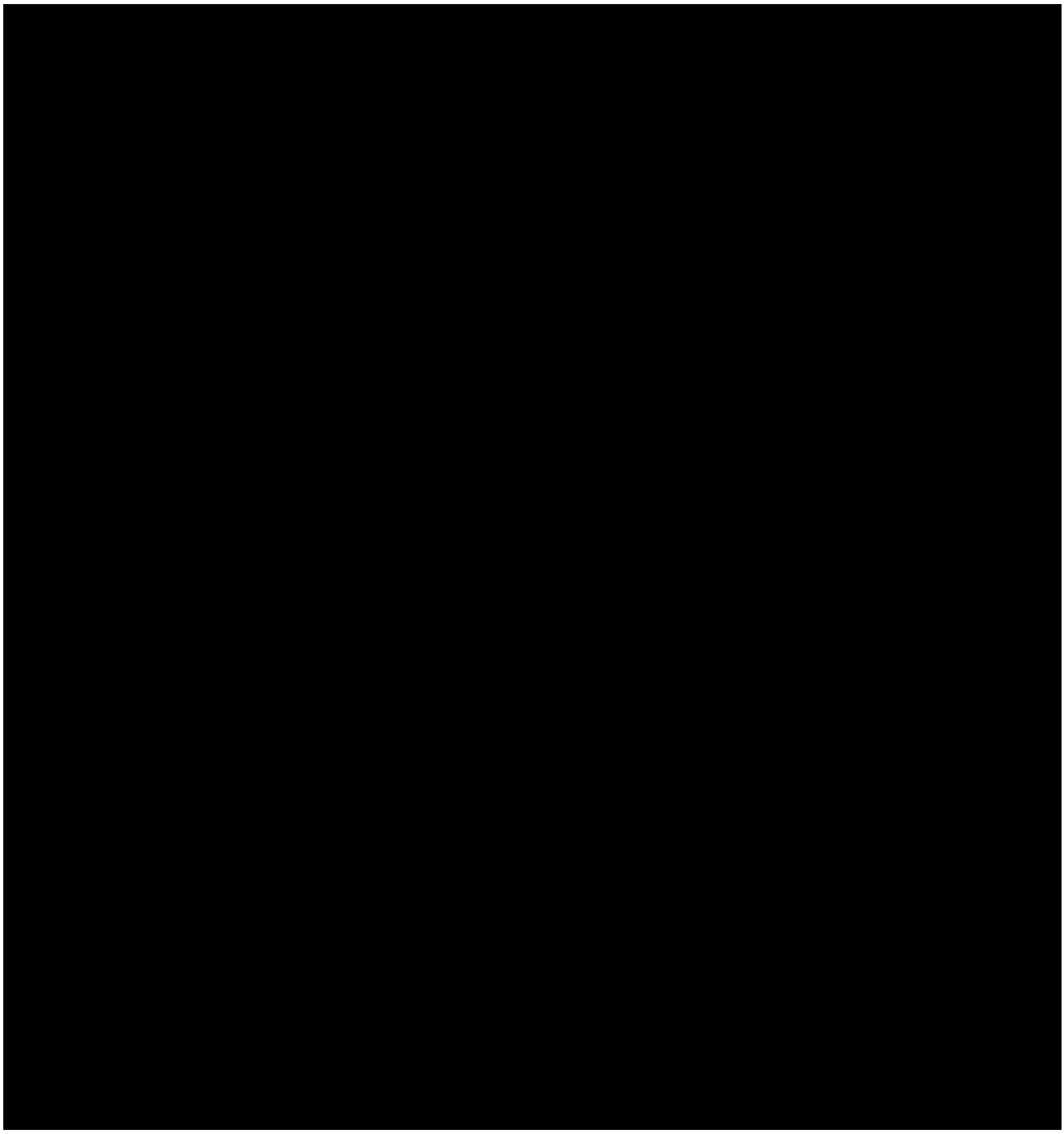
Figure 2.7-3 HAC Top End Drop (Case HE1) Acceleration Time-History

Figure 2.7-4 HAC Top End Drop (Case HE3) Acceleration Time-History

2.7.1.2 Side Drop

The package is evaluated for a 30-foot (9 m) HAC side drop considering the worst-case initial conditions in accordance with Regulatory Guide 7.8 [2.3]. The structural evaluation of the package for the HAC side drop test is described in the following sections.

2.7.1.2.1 Impact Limiter Evaluation



2.7.1.2.2 OSV and CCV Stress Evaluation

[redacted]

2.7.1.2.3 Shield Insert Stress Evaluation

[redacted]

Table 2.7-6 HAC Side Drop Impact Limiter Analysis Results

[redacted]

Table 2.7-7 HAC Side Drop Stress Summary

[redacted]

Figure 2.7-5 HAC [redacted] Side Drop (Case HS2) Impact Limiter Deformation

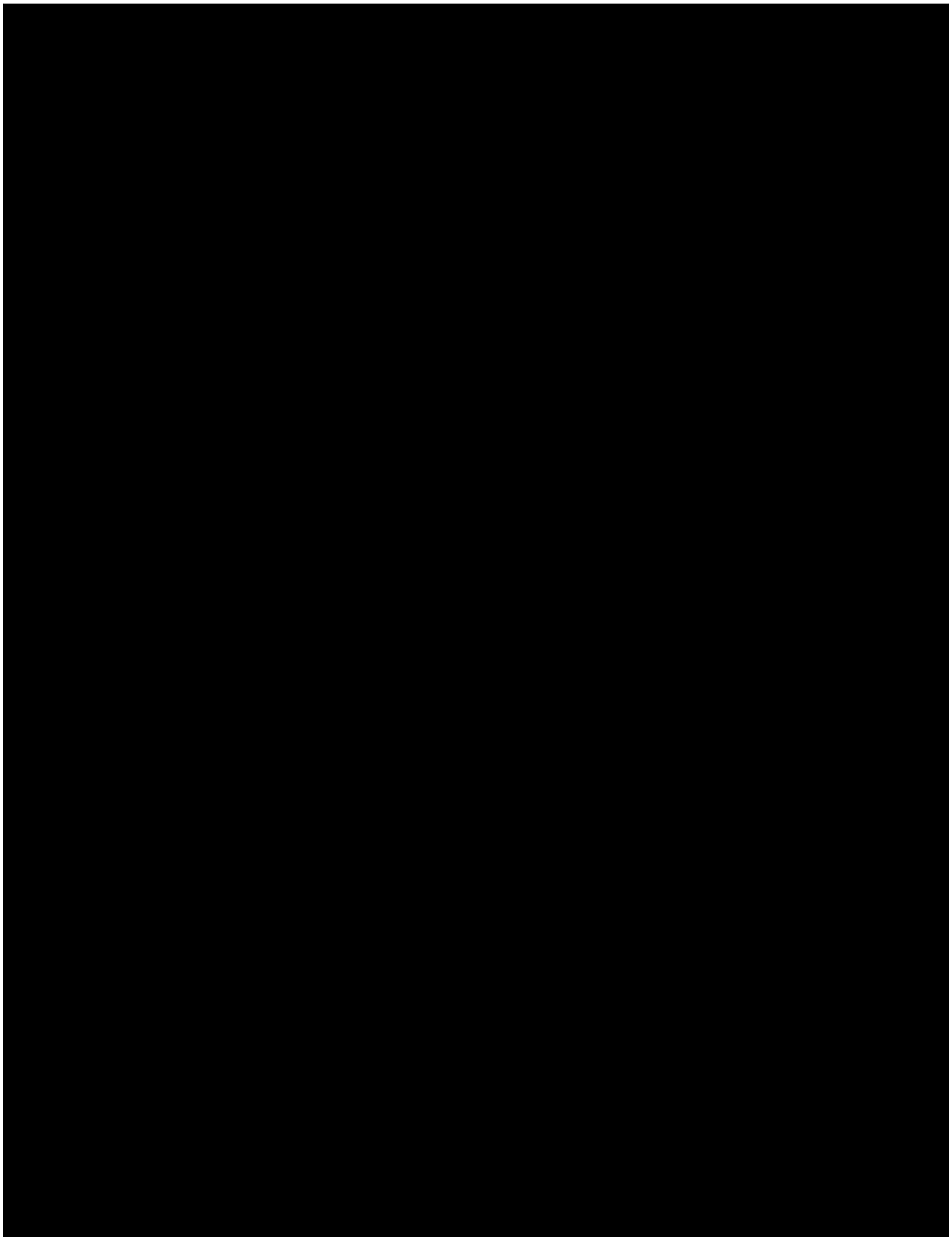
Figure 2.7-6 HAC [redacted] Side Drop (Case HS1) [redacted] Acceleration Time-History

Figure 2.7-7 HAC [redacted] Side Drop (Case HS3) [redacted] Acceleration Time-History

2.7.1.3 Corner Drop

The package is evaluated for a 30-foot (9 m) HAC corner drop considering the worst-case initial conditions in accordance with Regulatory Guide 7.8 [2.3]. The rigid-body dynamic response of the package to HAC top and bottom corner free drops will be essentially identical due to axial symmetry. Furthermore, the stresses in the CCV and OSV closure bolts due to the HAC top corner drop are expected to be higher than those due to the HAC bottom corner drop because the CCV and OSV lids and closure bolts support the combined inertial loading from their own masses and that of the contents under the HAC top corner drop, whereas they only support the inertial loading from their own masses under the HAC bottom corner drop. Therefore, the drop analysis of the packaging is only performed for the HAC top corner free drop.

2.7.1.3.1 Impact Limiter Evaluation



2.7.1.3.2 OSV and CCV Stress Evaluation

[redacted]

2.7.1.3.3 CCV Shell Buckling Evaluation

[redacted]

2.7.1.3.4 Shield Insert Stress Evaluation

[redacted]

Table 2.7-8 HAC Corner Drop Impact Limiter Analysis Results

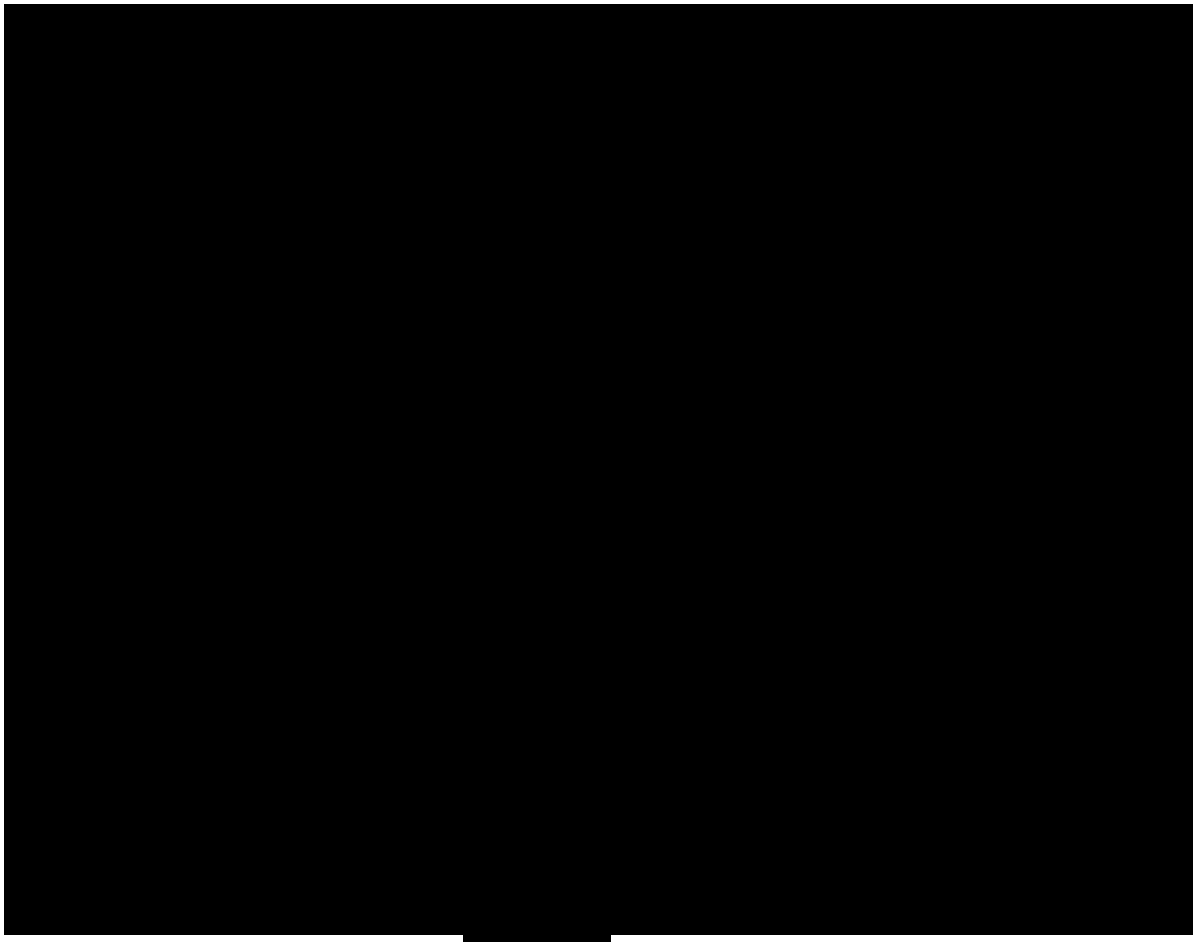


Figure 2.7-8 HAC Top Corner Drop (Case HC2) Impact Limiter Deformation

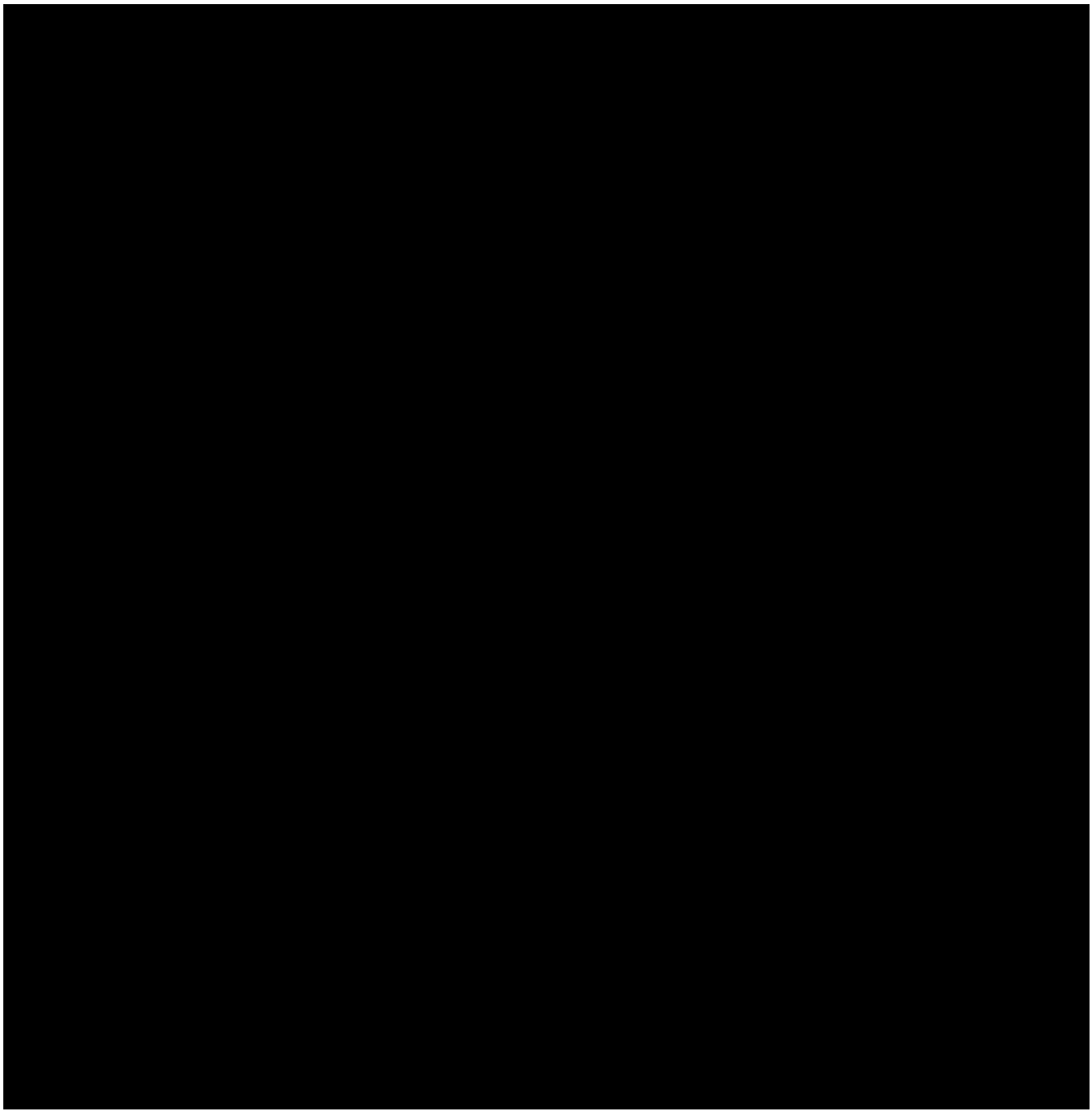
Figure 2.7-9 HAC Top Corner Drop (Case HC1) Acceleration Time-History

Figure 2.7-10 HAC Top Corner Drop (Case HC3) Acceleration Time-History

2.7.1.4 Oblique Drop

The package is evaluated for a 30-foot (9 m) HAC oblique drop considering the worst-case initial conditions in accordance with Regulatory Guide 7.8 [2.3]. The structural evaluation of the package for the HAC oblique drop test is described in the following sections.

2.7.1.4.1 Impact Limiter Evaluation



[redacted]

2.7.1.4.2 Stress Evaluation

[redacted]

Table 2.7-9 HAC Oblique Drop Impact Limiter Analysis Results

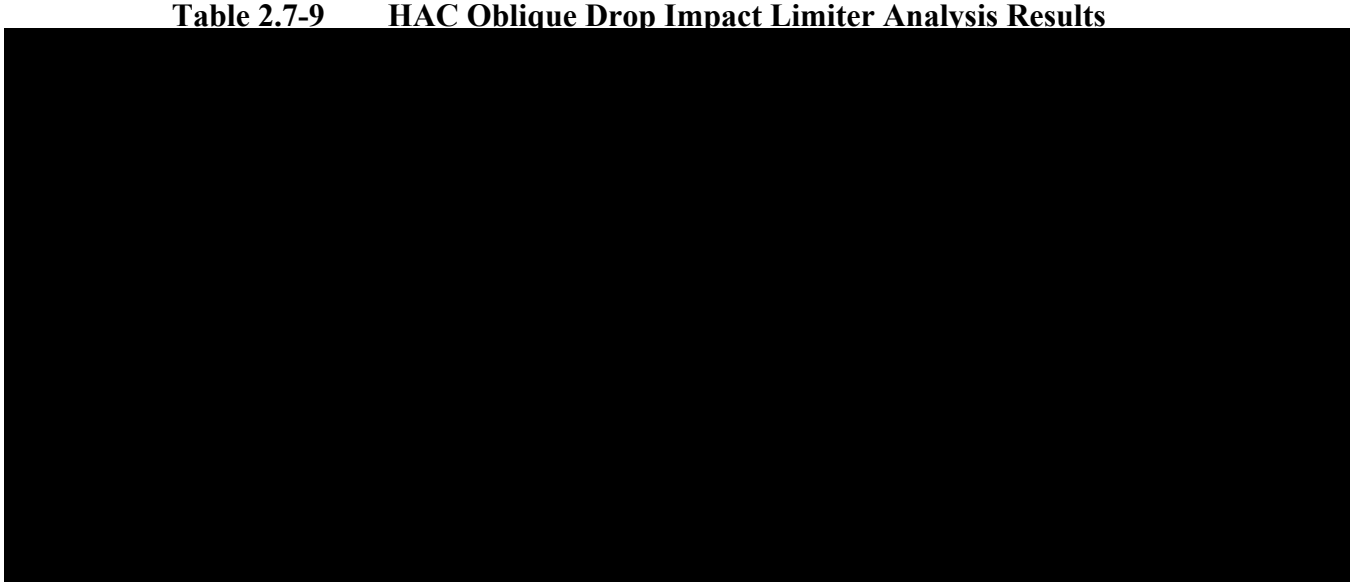


Figure 2.7-11 HAC 5° Oblique Drop (Case HO1) Impact Limiter Deformations

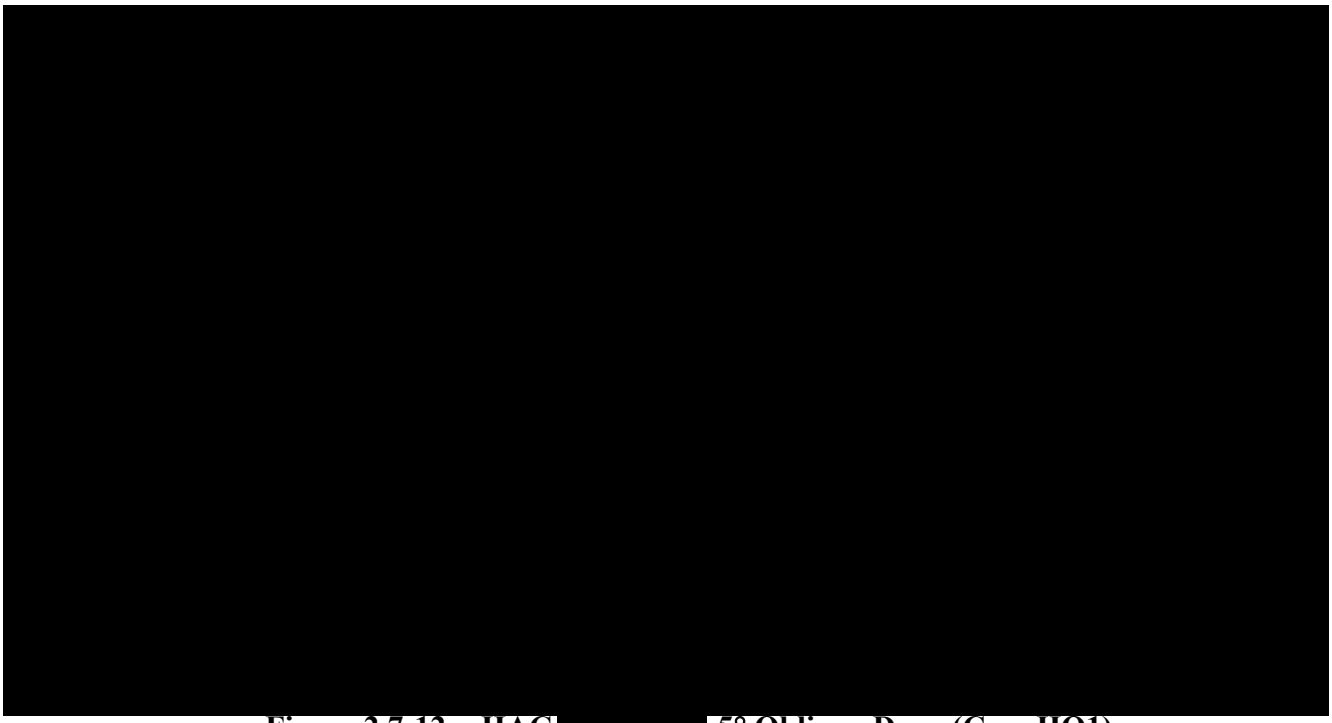


Figure 2.7-12 HAC 5° Oblique Drop (Case HO1) Acceleration Time-History

Figure 2.7-13 HAC 10° Oblique Drop (Case HO2) Impact Limiter Deformation

Figure 2.7-14 HAC 10° Oblique Drop (Case HO2) Acceleration Time-History

2.7.1.5 Summary of Results

The structural evaluation of the packaging for the HAC free drop test of 10 CFR 71.73(c)(1) shows that the applicable structural design criteria is satisfied for all cases analyzed. The HAC free drop does not cause any significant permanent deformation in the OSV and CCV. The only significant package damage resulting from the HAC free drop occurs in the impact limiter outer shells and foam. The impact limiter damage resulting from each HAC free drop orientations is described as follows:

HAC End Drop:

The permanently deformed shape of the impact limiter following the hot/heavy HAC top end drop (Case HE2) is shown in Figure 2.7-2. The hot/heavy HAC end drop results in a maximum permanent deformation of the impact limiter end foam and outer shell of approximately 4.3 inches (11 cm), or 43% of the end foam thickness. The impact limiter deformation resulting from the HAC top end drop is considered in the package HAC thermal evaluation.

HAC Side Drop:

The permanently deformed shape of the impact limiter following the hot/heavy HAC side drop (Case HS2) is shown in Figure 2.7-5. The hot/heavy HAC side drop results in a maximum permanent deformation of the impact limiter end foam and outer shell of approximately 6.6 inches (17 cm), or 55% of the side foam thickness.

HAC Corner Drop:

The permanently deformed shape of the impact limiter following the hot/heavy HAC top corner drop (Case HC2) is shown in Figure 2.7-8. The hot/heavy HAC corner drop results in a maximum permanent deformation of the impact limiter corner foam and outer shell of approximately 14.5 inches (37 cm).

HAC Oblique Drop:

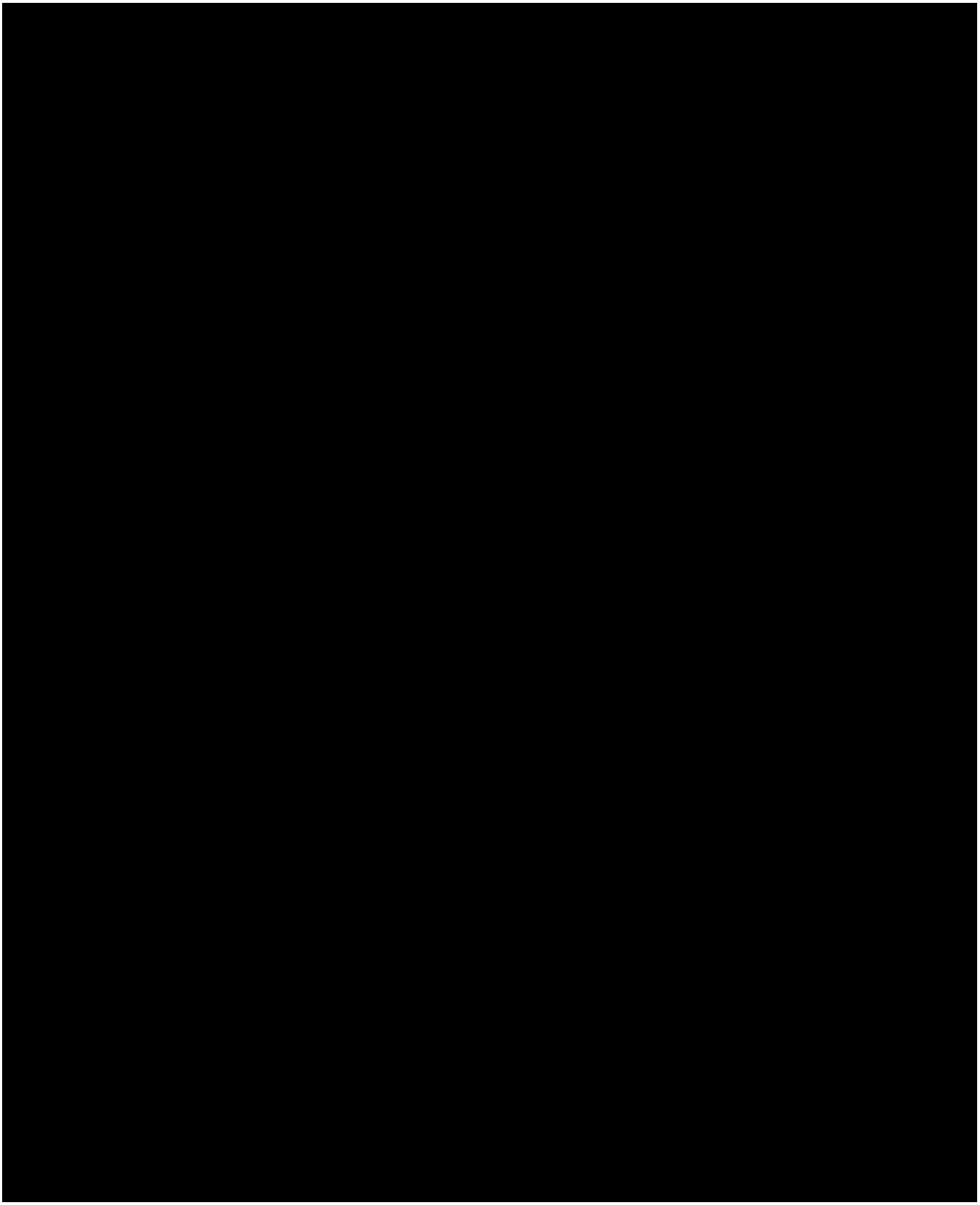
The results of the HAC oblique drop analysis show the package deformations and accelerations are bounded by the HAC side drop. Furthermore, the maximum tensile forces in the CCV and OSV bolts due to delayed impacts are bounded by those due to the HAC corner drop.

2.7.2 Crush

The crush test of 10 CFR 71.73(c)(2) is required only when the specimen has a mass not greater than 1,100 pounds (500 kg), an overall density not greater than 62.4 lb/ft^3 (1,000 kg/m^3) based on external dimensions, and radioactive contents greater than 1,000 A_2 not as a special form radioactive material. The OPTIMUS®-H package weighs more than 1,100 pounds (500 kg). Therefore, the crush test is not required.

2.7.3 Puncture

In accordance with 10 CFR 71.73(c)(3), the package is evaluated for a 1 m (40 in) free drop in a position for which maximum damage is expected, onto the upper end of a solid, vertical, cylindrical, mild steel bar, mounted on an essentially unyielding horizontal surface. The bar must be 15 cm (6 in) in diameter, with the top horizontal and its edge rounded to a radius of not more than 6 mm (0.25 in), and a length as to cause maximum damage to the package, but not less than 20 cm (8 in) long. The puncture drop test is performed in sequence following the HAC free drop test in accordance with 10 CFR 71.73(a). Therefore, the package damage resulting from the HAC free drop is considered in the HAC puncture drop evaluation. The maximum extent of damage sustained by the impact limiter for each HAC free drop orientation is discussed in Section 2.7.1.5.



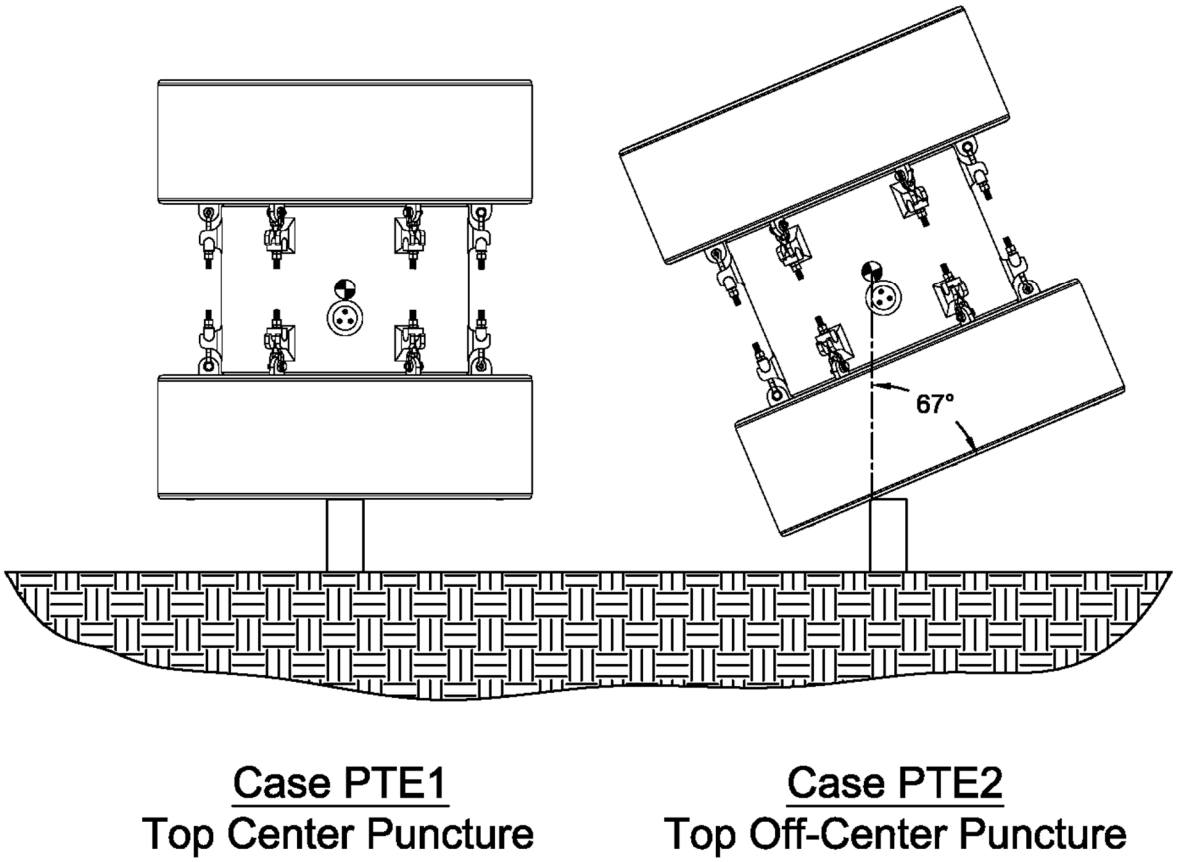


Figure 2.7-15 HAC Puncture Drop Top End Impact Orientations

Figure 2.7-16 Cumulative Impact Limiter Deformation - HAC Top End Drop and HAC Puncture Center Impact

Figure 2.7-17 Impact Limiter Deformation - HAC Top End Off-Center Puncture Impact

2.7.4 Thermal

In accordance with 10 CFR 71.73(c)(4), the package is designed to withstand the 30-minute fire with the flame temperature of 1,475°F (800°C). This section presents the structural evaluation of the package for the HAC thermal loading. The package temperatures and pressure resulting from the HAC thermal test are discussed in Section 2.7.4.1. Differential thermal expansion between the packaging components due to the HAC thermal loading is discussed in Section 2.7.4.2. The stresses in the packaging components due to the HAC thermal loading are evaluated in Section 2.7.4.3. Compliance with the applicable structural design criteria and the applicable regulatory performance requirements is discussed in Section 2.7.4.4.

2.7.4.1 Summary of Pressures and Temperatures

The top and bottom ends of the OSV are insulated from the full effects of the HAC fire by the impact limiters and the CCV is further insulated from the full effects of the HAC fire by the CCV. The thermal evaluation of the package for the HAC fire shows that, while the outer surface of the OSV reaches a peak temperature of approximately 801°F (427°C) during the HAC fire transient, the peak temperature of the CCV only reaches 363°F (184°C). As shown in Section 3.4.3.2, the maximum internal pressure developed in the CCV during the HAC thermal test, accounting for vapor pressure, addition of radiolytic gases, and increased temperature of the cavity gases due to the fire, is 70.1 psig (483 kPa). As discussed in Section 4.5.5.1, increased internal pressure from released contents of ruptured non-compliant TRU waste items, including aerosol cans filled with compressed or liquified gas propellant or standard DOE 3E lecture bottles filled with flammable gas or unknown contents, results in a maximum internal pressure in the CCV of 167.8 psig (1,157 kPa). Finally, as discussed in Section 4.5.5.2, the maximum CCV internal pressure resulting from potential combustion of non-compliant TRU waste contents is 161 psig (1,110 kPa). Therefore, the maximum CCV internal pressure for all HAC scenarios is much lower than the conservative HAC design pressure of 225 psi (1,551 kPa) gauge used for the structural evaluation of the CCV.

2.7.4.2 Differential Thermal Expansion Stress

Differential thermal expansion in the packaging components due to the HAC thermal loading causes the clearances between the packaging components to increase. The HAC thermal evaluation shows that the temperature of the OSV shell is higher than that of the CCV shell during the fire event. Following the fire event, the temperature gradients between the CCV and OSV remain bounded by those resulting from NCT heat. Therefore, the differential thermal expansion between the CCV and OSV during the HAC fire is expected to be bounded by the results for NCT heat from Section 2.6.1.2.

2.7.4.3 Stress Calculations

The stresses in the package resulting from temperature loading are classified as secondary and need not be evaluated for HAC in accordance with the ASME Code. The only significant primary stresses in the packaging resulting from the HAC fire are due to increased internal pressure loading resulting from elevated temperature of the cavity contents and fill gas during the fire transient. As discussed in Section 3.4.3.2, the maximum internal pressure resulting from the HAC fire is 70.1 psig for TRU waste (Content 1-1). For non-compliant TRU waste (Content IDs 1-2A, 1-2B, and 1-2C) the maximum internal pressure is limited to 225 psi (1551 kPa) gauge to allow for increased pressure resulting from the release of compressed gas or expansion of liquified gas inside aerosol cans or Lecture bottles. [redacted]

[redacted]

2.7.4.4 Comparison with Allowable Stresses

The results of the structural evaluation for the HAC thermal test demonstrate the packaging satisfies the applicable HAC allowable stress design criteria. The HAC thermal loading does not cause any significant permanent deformation of the CCV or OSV, nor does it substantially reduce the effectiveness of the packaging. The evaluation shows that no inelastic deformation of the CCV closure bolts results from the HAC thermal loading. Thus, containment will be maintained under HAC thermal loading, and there will be no loss or dispersal of radioactive contents. The damage to the impact limiters resulting from HAC free drop loading is considered in the HAC shielding evaluation, which demonstrates that the external dose rate limit requirements of 10 CFR 71.51(a)(2) are satisfied. Therefore, the package complies with the requirements of 10 CFR 71.51(a)(2) when subjected to the HAC thermal test of 10 CFR 71.73(c)(4).

Table 2.7-10 HAC Pressure Stress Summary

2.7.5 Immersion – Fissile Material

The criticality evaluation presented in Chapter 6 considers the effect of water in-leakage. Thus, the requirements of 10 CFR 71.73(c)(5) do not apply.

2.7.6 Immersion – All Packages

In accordance with 10 CFR 71.73(c)(6), an undamaged package is subjected to a water pressure equivalent to immersion under a head of water of at least 50 feet (15 m), or an equivalent external pressure load of 21.7 psi (150 kPa) gauge. A 21.7 psi (150 kPa) gauge external pressure load has negligible effects on the OPTIMUS®-H package and is bounded by the 290 psi (2 MPa) external pressure load evaluated in Section 2.7.7. Therefore, no further evaluation is required for this test.

2.7.7 Deep-Water Immersion Test (for Type B Packages Containing more than 10^5 A_2)

In accordance with 10 CFR 71.61, a Type B package containing more than 10^5 A_2 must be designed so that its undamaged containment system can withstand an external water pressure of 290 psi (2 MPa) for a period of not less than 1 hour without collapse, buckling, or inleakage of water. This section provides the analysis of the package containment system that demonstrates compliance with the deep-water immersion test requirements of 10 CFR 71.61.

[redacted]

Containment System Stress Evaluation

[redacted]

Buckling Evaluation

Table 2.7-11 Deep Water Immersion Test Stress Summary

Table 2.7-12 CCV Shell Buckling Summary for Deep Water Immersion Test

2.7.8 Summary of Damage

The preceding structural evaluation demonstrates the package satisfies the applicable structural design criteria and the performance requirements of c for the HAC test sequence of 10 CFR 71.73. The condition of the package after each test of the HAC sequence, based on the sequential application of the free drop, puncture, and thermal tests, is summarized as follows.

HAC Free Drop

The HAC free drop test of 10 CFR 71.73(c)(1) does not cause any significant permanent deformation in the OSV and CCV. No inelastic deformation of the CCV closure bolts results from the HAC free drop test. The only significant package damage resulting from the HAC free drop occurs in the impact limiters, according to their design function. The impact limiter damage resulting from each of the HAC free drop orientations is discussed in Section 2.7.3. The HAC corner drop is shown to cause the greatest extent of damage to the impact limiters. The HAC corner drop results in a maximum permanent crush distance of 12.7 inches (32 cm) to the impact limiter.

HAC Puncture

The package is subjected to the HAC puncture test of 10 CFR 71.73(c)(3), considering the damage sustained from the HAC free drop of 10 CFR 71.73(c)(1). The damage to the package resulting from the HAC free drop does not affect the package's ability to withstand the HAC puncture. As discussed in Section 2.7.3, the extent of package damage resulting from the HAC puncture test is limited to local deformation (i.e., denting) of the impact limiter outer shell and foam and localized tearing of the impact limiter outer shell at the point of impact with the puncture bar.

The cumulative damage of the package resulting from the HAC free drop and HAC puncture tests is considered in the HAC thermal evaluation presented in Section 3.4. The HAC thermal evaluation is performed for the worst-case damage scenario, consisting of top end free drop and top end puncture drop damage. The extent of impact limiter damage assumed in the HAC thermal analysis bounds the effects of the cumulative damage that result from the HAC free drop and HAC puncture tests. The results of the HAC thermal evaluation demonstrate that the cumulative damage does not affect the package's ability to satisfy the performance requirements of 10 CFR 71.

HAC Thermal

The package is subjected to the HAC thermal test of 10 CFR 71.73(c)(4), considering the damage sustained from the HAC free drop of 10 CFR 71.73(c)(1) and HAC puncture of

10 CFR 71.73(c)(3). The extent of package damage resulting from the HAC free drop and HAC puncture tests does not affect the package's ability to withstand the HAC thermal test. This is demonstrated by the HAC thermal evaluation, which considers the cumulative package damage resulting from the HAC free drop and HAC puncture tests. The impact limiter thermal relief plugs are designed to fail during the HAC thermal test to allow gases generated by the foam material to escape, should the impact limiter outer shell not be perforated by the HAC puncture test. The HAC thermal test will cause some charring to the outer portion of the impact limiter foam. However, the foam will provide sufficient thermal protection to prevent the temperatures in the OSV and CCV from exceeding the temperature limits. The structural evaluation of the packaging for the temperature and pressure loads resulting from the HAC thermal test shows that no additional damage of the OSV and CCV will result from the HAC thermal test. As discussed in Section 2.7.4.3, the CCV bolts satisfy the applicable HAC allowable stress design criteria and will maintain leak-tight containment under the worst-case HAC thermal loading.

2.8 Accident Conditions for Air Transport of Plutonium

Not applicable.

This page intentionally left blank.

2.9 Accident Conditions for Fissile Material Packages for Air Transport

Not applicable.

This page intentionally left blank.

2.10 Special Form

The packaging containment system is leaktight and no credit is taken for special form contents. Therefore, this section is not applicable.

This page intentionally left blank.

2.11 Fuel Rods

Containment of the radioactive materials is provided by the CCV containment boundary, as defined in Chapter 4 of this SAR. Analyses of the CCV containment boundary for all NCT and HAC demonstrate containment will not be breached.

As discussed in Chapter 6 of this SAR, no credit is taken for geometry control provided by fuel rods or other non-fuel components of fuel waste contents of the package. Therefore, no further evaluation of fuel rod integrity is required.

This page intentionally left blank.

2.12 Appendix

2.12.1 References

[2.1] Regulatory Guide 7.9, *Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material*, Revision 2, March 2005.

[2.2] NUREG-2216, *Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Materials- Final Report*, U.S. Nuclear Regulatory Commission, Spent Fuel Project Office, August 2020.

[2.3] Regulatory Guide 7.8, *Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material*, Revision 1, U.S. Nuclear Regulatory Commission, Office of Standards Development, March 1989.

[2.4] Regulatory Guide 7.6, *Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels*, Revision 1, March 1978.

[2.5] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, *Class 1 Components*, 2010 Edition with 2011 Addenda.

[2.6] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Appendix F, *Rules for Evaluation of Service Loadings with Level D Service Limits*, 2010 Edition with 2011 Addenda.

[2.7] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NF, *Supports*, 2010 Edition with 2011 Addenda.

[2.8] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Code Cases: Nuclear Components, Case N-284-1, *Metal Containment Shell Buckling Design Methods, Class MC*, 2010 Edition with 2011 Addenda.

[2.9] W. C. Young, *Roark's Formulas for Stress & Strain*, McGraw-Hill Book Company, Sixth Edition.

[2.10] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section V, *Nondestructive Examination*, Current Edition.

[2.11] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Division 1, Appendix I, *Design Stress Intensity Values, Allowable Stresses, Material Properties, and Design Fatigue Curves*, 2010 Edition with 2011 Addenda.

[2.12] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, Part D, *Materials*, 2010 Edition with 2011 Addenda.

[2.13] Regulatory Guide 7.11, *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inch (0.1 m)*, U.S. Nuclear Regulatory Commission, Office of Standards Development, June 1991.

[2.14] Holman, W. R., and Langland, R. T., *Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick*, NUREG/CR-1815, UCRL-53013, U.S. Nuclear Regulatory Commission, August 1981.

[2.15] Fischer, L. E., and Lai, W., *Fabrication Criteria for Shipping Containers*, NUREG/CR-3854, UCRL-53544, U.S. Nuclear Regulatory Commission, March 1985.

[2.16] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Code Cases: Nuclear Components, Case N-670-1, *Use of Ductile Cast Iron Conforming to ASTM A 874/A 874M-98 or JIS G5504-2005 for Transport and Storage Containments*, January 4, 2008.

[2.17] ASTM International, A874/A874M-98, *Standard Specification for Ferritic Ductile Iron Castings Suitable for Low-Temperature Service*.

[2.18] Ductile Iron Society, *Ductile Iron Data for Design Engineers*, 2013 (www.ductile.org/didata/Section3/3part1.htm).

[2.19] General Plastics Manufacturing Co., Design Guide for Use of LAST-A-FOAM® FR-3700 for *Crash and Fire Protection of Radioactive Material Shipping Containers*, Revision iss001.

[2.20] Parker Hannifin Corporation, *Parker O-Ring Handbook*, ORD 5700/USA, 2001.

[2.21] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section IX, *Welding and Brazing Qualifications.* Latest Edition.

[2.22] Foley, J. T. and Gens, M. B., *Shock and Vibration Measurements during Normal Rail and Truck Transport*, www.osti.gov/servlets/purl/4701246.

[2.23] Blevins, R. D., *Formulas for Natural Frequency and Mode Shape*, Van Nostrand Reinhold Company, 1979.

[2.24] NUREG/CR-3966, *Methods for Impact Analysis of Shipping Containers*, UCID-20639, U. S. Nuclear Regulatory Commission, November 1987.

[2.25] ANSI N14.6, *Special Lifting Devices for Shipping Containers Weighing 10000 Pounds (4500 kg) or More*, American National Standards Institute, Inc., New York, 1993.

[2.26] American Society of Mechanical Engineers, "Design of Below-the-Hook Lifting Devices," ASME BTH-1-2005, 2005.

[2.27] American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section VIII, Division 2, Annex 3.D, Strength Parameters," 2010.

[2.28] Mok, G. C., et al., *Stress Analysis of Closure Bolts for Shipping Casks*, NUREG/CR-6007, UCRL-ID-110637, U.S. Nuclear Regulatory Commission, April 1992.

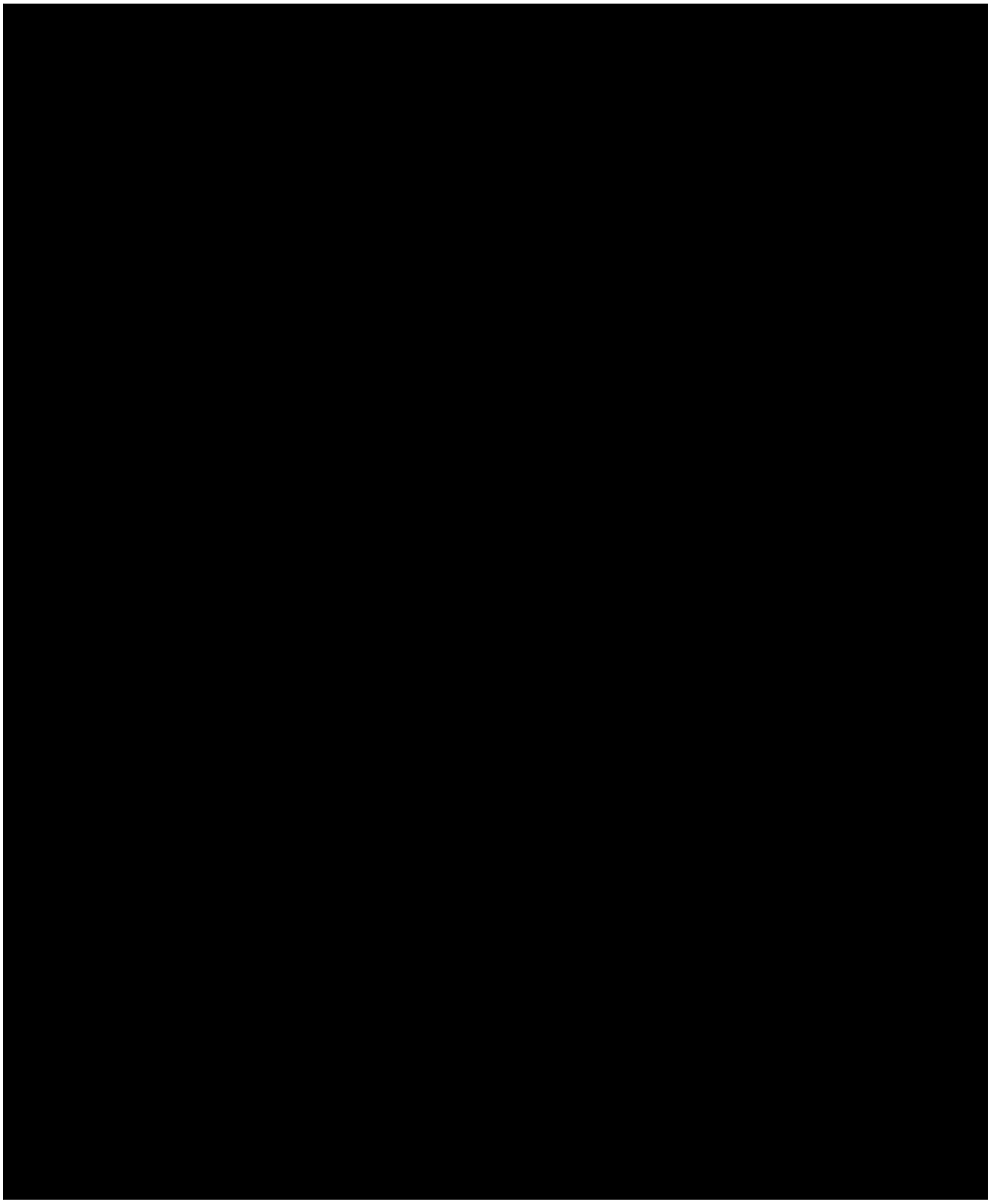
[2.29] Clements, et. al., EGG-WM-6503, September 1985, “TRU Waste Sampling Program: Volume I, Waste Characterization,” EG&G Idaho, Idaho Falls, Idaho.

[2.30] Roggenthen, et. al., RFP-4311, March 1989, "Waste Drum Gas Generation Sampling Program at Rocky Flats During FY 1988,".

[2.31] McAllister, et. al., Fundamentals of Combustion Processes, Springer, New York, 2011.

[2.32] U.S. Department of Transportation, Federal Aviation Administration, DOT/FAA/AR-05/14, Polymer Flammability, May 2005.

2.12.2 Computer Code Descriptions



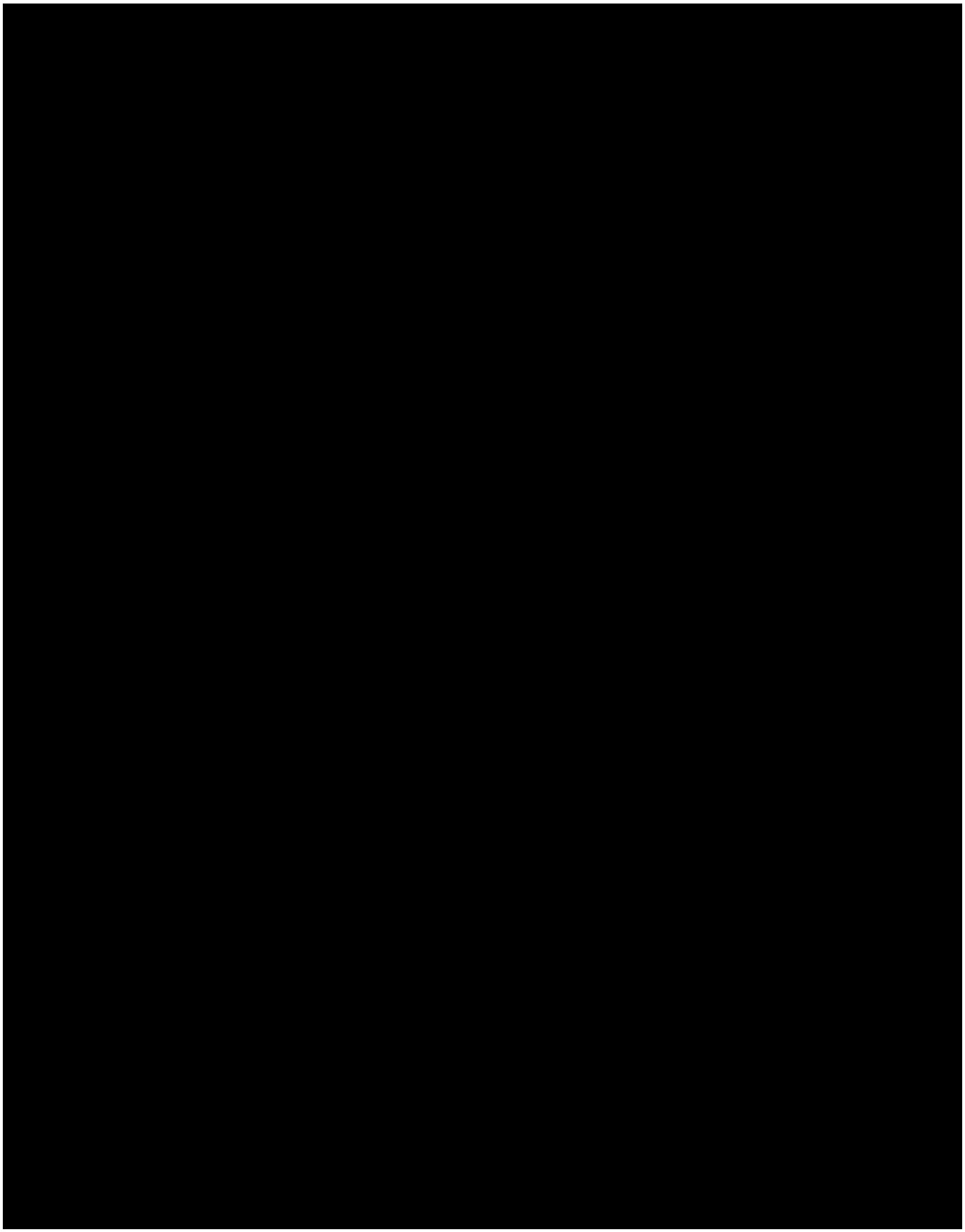
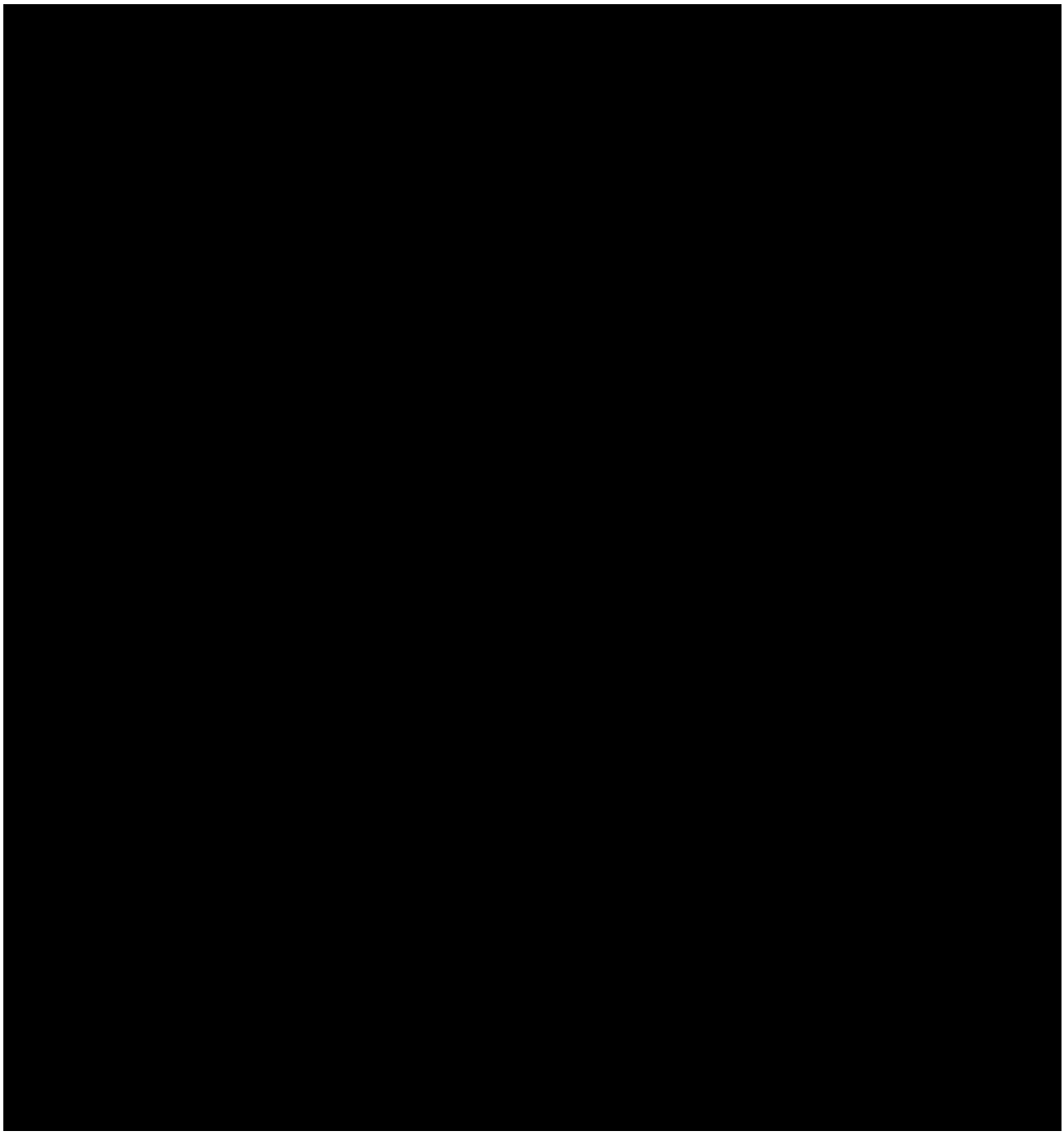


Table 2.12-1

Figure 2.12-1 Benchmark Comparison of HAC Side Drop Analysis and Test Results

2.12.4 Development of Equivalent Static Loads

The stresses in the CCV due to NCT and HAC free drop loading are calculated using equivalent-static linear-elastic finite element analyses. The equivalent-static acceleration loads for each NCT and HAC free drop test are equal to the peak rigid body accelerations of the packaging multiplied by a DLF that accounts for possible dynamic amplification within the packaging. The DLF is a function of the general shape of the rigid-body acceleration time-history pulse and the ratio of the duration of the rigid body acceleration time-history to the packaging period (t/T).



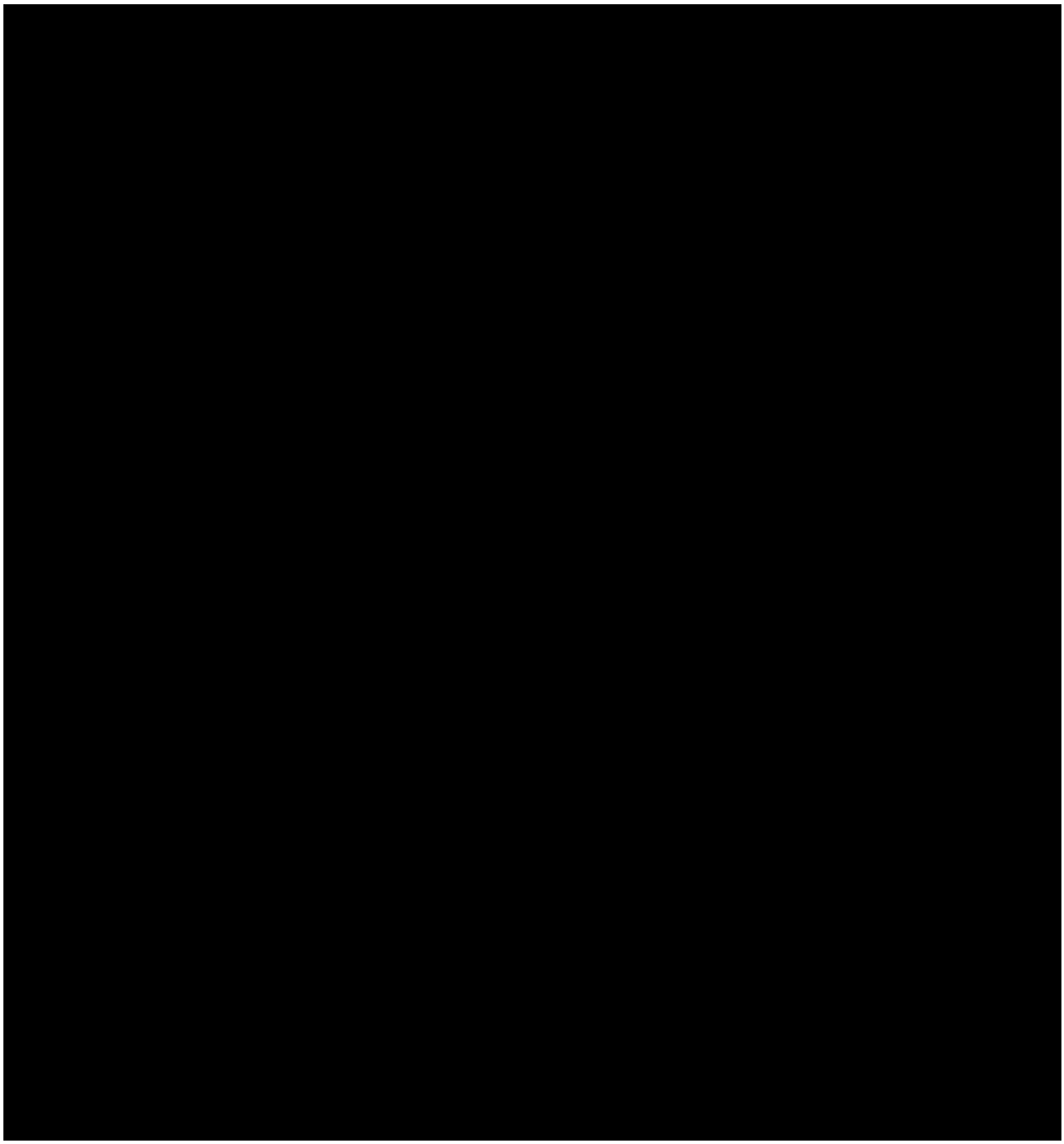


Figure 2.12-2

2.12.5 Closure Bolt Evaluation

The CCV and OSV closure bolts are designed in accordance with the requirements of NUREG/CR-6007 [2.28] to withstand the NCT loadings of SSR-6, §719 through 724 and 10 CFR 71.71, HAC loadings of SSR-6, §727 through 729 and 10 CFR 71.73, and special requirements for irradiated nuclear fuel shipments of SSR-6, §670 and 10 CFR 71.61. The following analyses demonstrate the ability of the closure bolts to meet the criteria as specified in NUREG/CR-6007. The load combinations are evaluated in accordance with Regulatory Guide 7.8 and as discussed in Section 2.1.2.1.

2.12.5.1 Geometric Parameters

The geometric parameters used for the evaluation of the closure bolts are summarized in Table 2.12-2.

2.12.5.2 Bolt Forces and Moments

The closure bolts are loaded by operational loads such as O-ring seal seating loads, bolt tightening pre-load, vibration, cask internal pressure, and differential thermal expansion, and by NCT and HAC free drop and puncture impact loads. The bolt forces and moments for each load are developed in the subsections that follow.

Since the closure lids and closure bolts are protected by the lip of the top forging ring and the closure bolt holes are oversized compared to the radial clearance between the closure lids and the respective bolt flange openings into which they fit, the closure bolts do not need to resist direct shear loads. Therefore, in accordance with Table 4.9 of NUREG/CR-6007 [2.28], evaluation for direct shear bolt forces is not required.

2.12.5.2.1 Preload

The closure bolt loads resulting from applied torque are evaluated in accordance with Section 4.2 of NUREG/CR-6007 [2.28]. Maximum and minimum torque values are evaluated based on the torque values specified on the general arrangement drawings included in Appendix 1.3.3. The maximum bolt torque is combined with NTC heat temperature loading to evaluate the maximum possible non-prying tensile load in the closure bolts. The minimum bolt torque is combined with cold temperature loading to evaluate the minimum seating loads.

The non-prying tensile force per bolt Fa is:

$$Fa = {}^{Q}/_{K \cdot Db}$$

where:

[redacted]

The torsional moment, Mtr, is:

$$Mtr = 0.5Q$$

The closure bolts are torqued incrementally using a star-pattern to achieve uniform bolt pre-loads and seal compression. Consequently, bolt prying loads due to pre-load is considered negligible. In accordance with Section 4.2 of NUREG/CR-6007 [2.28], the residual bolt pre-load is assumed equal to the applied bolt pre-load, conservatively assuming no relaxation of the bolt loads after the pre-load operation.

2.12.5.2.2 Gasket Load

The closure bolt loads resulting from gasket loads are evaluated in accordance with Section 4.3 of NUREG/CR-6007 [2.28]. The non-prying tensile force, Fa, and torsional moment, Mt, produced by the gasket seating operation are:

$$Fa = (\pi \cdot Dlg \cdot b \cdot y)/Nb$$

$$Mt = (0.5 \cdot \pi \cdot K \cdot Db \cdot Dlg \cdot b \cdot y)/Nb$$

Where the minimum design seating stress (y) and the effective gasket seating width (b) are defined in accordance with Appendix E of the ASME B&PV Code and Dlb and Nb are the closure bolt geometric parameters from Table 2.12-2. The elastomeric O-rings used for the CCV and OSV lids are self-energizing seals. Per Table E-1210-1 of the ASME B&PV Code, the seating stress for self-energizing seals is zero. Therefore, the bolt loads resulting from gasket loads are zero.

2.12.5.2.3 Pressure Load

The closure bolt loads resulting from pressure loads are evaluated in accordance with Section 4.4 of NUREG/CR-6007 [2.28]. The non-prying tensile force, Fa, shear force, Fs, fixed-edge closure lid force, Ff, and fixed edge closure lid moment, Mf, due to pressure loading are:

$$Fa = [(\pi \cdot Dlg^2 \cdot (Pli - Plo)]/(4 \cdot Nb)$$

$$Fs = [(\pi \cdot El \cdot tl \cdot (Pci - Pco) \cdot Dlb^2]/[2 \cdot Nb \cdot Ec \cdot tc \cdot (1 - NUl)]$$

$$Ff = [Dlb \cdot (Pli - Plo)]/4$$

$$Mf = [Dlb^2 \cdot (Pli - Plo)] / 32$$

The net pressure load across the CCV lid (i.e., Pli - Plo) and CCV shell (i.e., Pci - Pco) is 100 psig for MNOP, 111.2 psig for reduced external pressure loading, and 225 psig for HAC thermal. The geometric parameters are summarized Table 2.12-2 and material properties used for NCT heat, NCT cold, and HAC thermal are summarized in Table 2.12-3.

2.12.5.2.4 Temperature Load

The closure bolt loads resulting from temperature loads are evaluated in accordance with Section 4.5 of NUREG/CR-6007 [2.28]. The non-prying tensile force, Fa, shear force, Fs, fixed-edge closure lid force, Ff, and fixed edge closure lid moment, Mf, due to temperature loading are:

$$\text{Fa} = [(0.25\pi \cdot Db^2 \cdot Eb \cdot (al \cdot Tl - ab \cdot Tb)]$$

$$\text{Fs} = (\pi \cdot El \cdot tl \cdot Dlb \cdot (al \cdot Tl - ac \cdot Tc)] \Big/ [Nb \cdot (1 - NUl)]$$

$$\text{Ff} = 0$$

$$\text{Mf} = (El \cdot al \cdot tl^2 \cdot (Tlo - Tli)] \Big/ [12 \cdot (1 - NUl)]$$

Where the geometric parameters are summarized Table 2.12-2 and CCV and OSV material properties used for NCT heat, NCT cold, and HAC thermal are summarized in Table 2.12-3. In cases resulting in negative values of prying loads, the prying loads are assumed equal to zero.

2.12.5.2.5 Vibration Load

The closure bolt loads resulting from vibration loads are evaluated in accordance with Section 4.8 of NUREG/CR-6007 [2.28]. The tie-down acceleration loads from SSR-6, §612 and 10 CFR 71.45(b)(1) are conservatively considered for vibration loading of the bolts. Longitudinal and transverse vibration loads will not result in any bolt loads due to the protected lid designs. However, the vertical load will produce a tensile bolt load. Therefore, the closure bolts are evaluated for a 2g vertical acceleration. The non-prying tensile force, Fa, and fixed edge closure lid moment, Mf, due to vibration loading, assuming a vibration transmissibility (VTR) between the supporting wall and the lid, of 1.0, are:

$$\text{Fa} = (2g \cdot Wl) \Big/ Nb$$

$$\text{Fs} = 0$$

$$\text{Mf} = 2g \cdot Wl \Big/ 8\pi$$

Where the geometric parameters are summarized Table 2.12-2.

2.12.5.2.6 Impact Load

For the CCV and OSV bolts, the maximum tensile forces are obtained directly from [redacted] impact analyses. The results of the [redacted] drop analysis show that the maximum CCV bolt tensile forces due to the NCT and HAC free drop are 1.9 kip and 8.3 kip, respectively. Similarly, the results of the [redacted] drop analysis show that the maximum OSV bolt tensile forces due to the NCT and HAC free drop are 7.7 kip and 27.0 kip, respectively. Bounding CCV bolt tensile forces of 2.0 kip and 10.0 kip are conservatively assumed for NCT and HAC free drop analyses, respectively. Similarly, bounding OSV bolt tensile forces of 8.0 kip and 30.0 kip are conservatively assumed for NCT and HAC free drop analyses, respectively.

2.12.5.3 Bolt Stresses

Per Table 5.1 of NUREG/CR-6007 [2.28], the calculation of the closure bolt tensile, shear, bending, and torsional stresses, and stress intensity for combined stresses, are based on the load combinations presented in Section 2.1.2.1. The closure bolt tensile stress, direct shear stress, bending stress, torsional shear stress, and stress intensity in the CCV and OSV closure bolts are calculated in accordance with NUREG/CR-6007 as follows:

Tensile Stress: $Sba = (1.2732)\,{}^{Fa}/_{D^2}$

Shear Stress: $Sbs = (1.2732)\,{}^{Fs}/_{D^2}$

Bending Stress: $Sbb = (10.186)\,{}^{Mbb}/_{D^3}$

Torsional Stress: $Sbt = (5.093)\,{}^{Mtr}/_{D^3}$

Stress Intensity: $Sbi = \sqrt{(Sba + Sbb)^2 + 4(Sbs + Sbt)^2}$

Where the bolt diameter, D, used for the CCV closure bolt stress calculation is [redacted] For the OSV closure bolts, the bolt diameter used for stress calculation is calculated as follows:

$D = D_b - 0.9743p = 1.11$ in.

$p = 1/n$, Bolt thread pitch

n = [redacted] Number of threads per unit length

2.12.5.4 Bolt Allowable Stresses

The CCV closure bolts are designed in accordance with the containment system allowable stress design criteria summarized in Table 2.1-3. For NCT, the average tensile stress, average shear stress, and maximum stress intensity in the CCV closure bolts are limited to S_m, $0.6S_m$, and $1.35S_m$, respectively. The design stress, S_m, of the CCV closure bolt [redacted] material at a bounding temperature of 350°F (177°C) is 63.8 ksi (440 MPa). Therefore, the allowable average tensile stress, average shear stress, and stress intensity for the CCV closure bolts for NCT are 62.5 ksi (431 MPa), 37.5 ksi (259 MPa), and 84.4 ksi (582 MPa) respectively.

For the CCV closure bolts under HAC the average tensile stress is limited to the lesser of $0.7S_u$ and S_y, and the average shear stress is limited to the lesser of $0.42S_u$ and $0.6S_y$. The yield strength, S_y, and tensile strength, S_u, of the CCV closure bolt [redacted] material at a bounding temperature of 350°F (177°C) are 95.7 ksi (660 MPa) and 125.0 ksi (862 MPa), respectively. Therefore, the allowable average tensile stress and average shear stress for the CCV closure bolts for HAC are 87.5 ksi (603 MPa) and 52.5 ksi (362 MPa) respectively.

The OSV closure bolts are designed in accordance with the non-containment component allowable stress design criteria summarized in Table 2.1-4. For NCT, the OSV closure bolt average tensile stress limited to $S_u/2$ and the average shear stress is limited to $0.62S_u/3$. Per Table 2.2-6, the tensile strength, S_u, of the OSV closure bolt [redacted] material at a bounding temperature of 350°F (177°C) is 150.0 ksi (1,034 MPa). Therefore, the allowable average tensile stress and average shear stress for the OSV closure bolts for NCT are 75.0 ksi (517 MPa) and 31.0 ksi (214 MPa) respectively.

For the OSV closure bolts under HAC the average tensile stress is limited to the lesser of $0.7S_u$ and S_y, and the average shear stress is limited to the lesser of $0.42S_u$ and $0.6S_y$. The yield strength, S_y, and tensile strength, S_u, of the OSV closure bolt [redacted] material at a bounding temperature of 350°F (177°C) are 113.0 ksi (779 MPa) and 150.0 ksi (1,034 MPa), respectively. Therefore, the allowable average tensile stress and average shear stress for the CCV closure bolts for HAC are 105.0 ksi (724 MPa) and 63.0 ksi (434 MPa) respectively.

Table 2.12-2 Closure Bolt Geometry and Material Properties

Table 2.12-3 Summary of Bolt Temperature Load Parameters

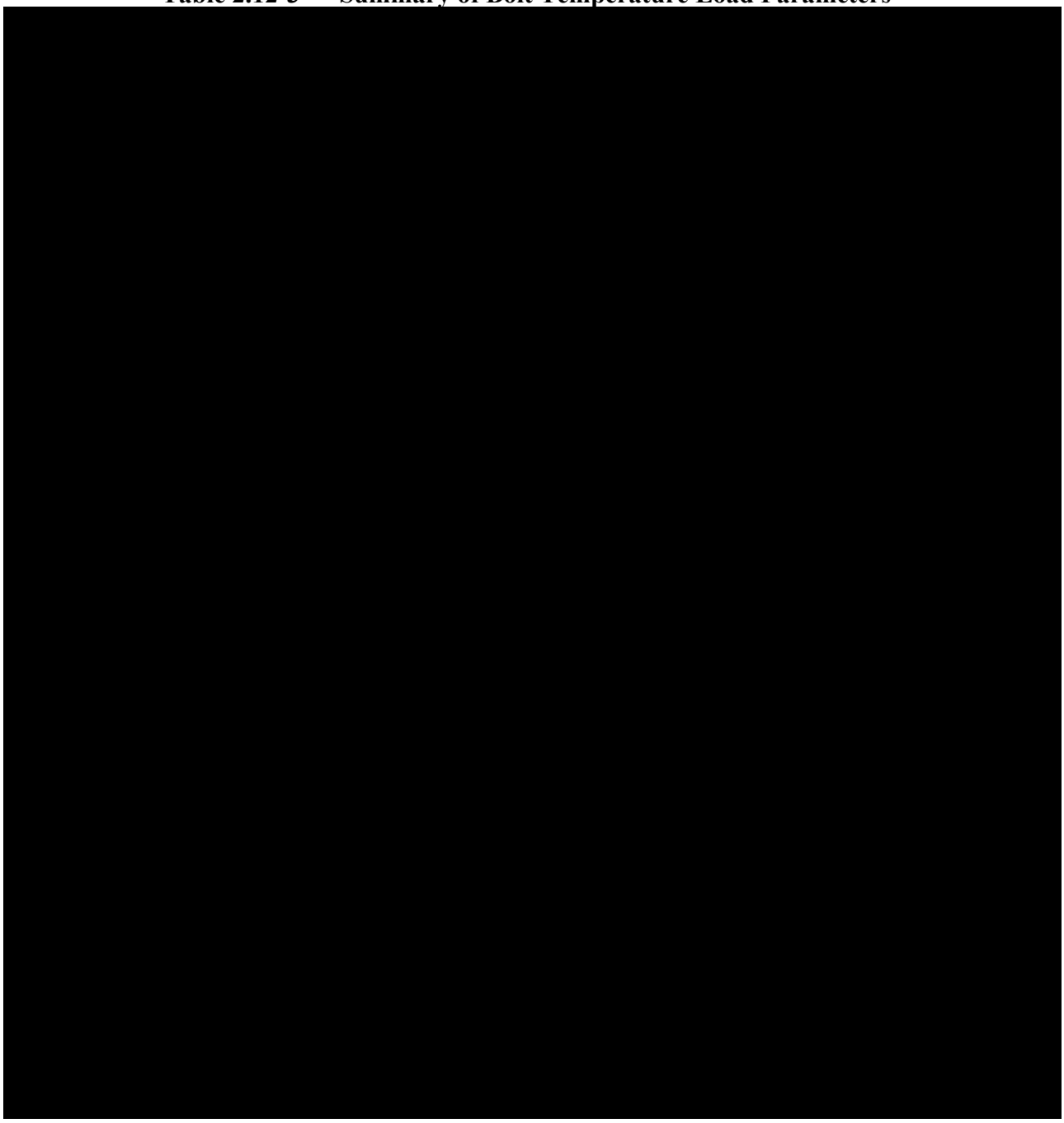


Table 2.12-4 Closure Bolt Loads

Table 2.12-5 Closure Bolt Combined Loads

Table 2.12-6 Closure Bolt NCT Stresses and Interaction Ratios

Table 2.12-7 Closure Bolt HAC Stresses and Interaction Ratios

Chapter 3
Thermal Evaluation

Table of Contents

3 THERMAL EVALUATION 3-1
3.1 Description of Thermal Design 3.1-1
3.1.1 Design Features 3.1-1
3.1.2 Content's Decay Heat 3.1-2
3.1.3 Summary Tables of Temperatures 3.1-2
3.1.4 Summary Table of Maximum Pressures 3.1-3
3.2 Material Properties and Component Specifications 3.2-1
3.2.1 Material Properties 3.2-1
3.2.2 Component Specifications 3.2-1
3.3 Thermal Evaluation Under Normal Conditions of Transport 3.3-1
3.3.1 Heat and Cold 3.3-26
3.3.2 Maximum Normal Operating Pressure 3.3-32
3.4 Thermal Evaluation Under Hypothetical Accident Conditions 3.4-1
3.4.1 Initial Conditions 3.4-1
3.4.2 Fire Test Conditions 3.4-4
3.4.3 Maximum Temperatures and Pressure 3.4-6
3.4.4 Maximum Thermal Stresses 3.4-9
3.4.5 Accident Conditions for Fissile Material Packages for Air Transport 3.4-10
3.5 Appendix 3.5-1
3.5.1 References 3.5-1
3.5.2 Sensitivity Analyses of Modeling Parameters 3.5-2

List of Figures

Figure 3.3-1 [redacted] 3.3-19
Figure 3.3-2 Three-Dimensional Finite Element Model of Impact Limiters Shells..... 3.3-20
Figure 3.3-3 Exploded View of the CCV with Modeled TRU Waste in 110-Gallon Drum 3.3-21
Figure 3.3-4 Exploded View of the CCV with Modeled Fuel Waste..... 3.3-21
Figure 3.3-5 Thermal Contact Pairs in the NCT Model 3.3-22
Figure 3.3-6 Application of Convection Boundary Conditions for NCT (and Shade)..... 3.3-23
Figure 3.3-7 Heat Transfer Coefficients for General Standards (shade) and NCT 3.3-24
Figure 3.3-8 Heat Flux Boundary Conditions for NCT (200W) 3.3-25
Figure 3.3-9 Volumetric Heat Generation Boundary Conditions for NCT 3.3-25
Figure 3.3-10 NCT Steady-State Temperatures Fuel Waste (1500 W, He) 3.3-30
Figure 3.3-11 CCV Lid Temperatures, NCT, Fuel Waste, 1500 W Heat Flux 3.3-30
Figure 3.3-12 OSV Lid Temperatures, NCT, Fuel Waste, 1500 W Heat Flux 3.3-31
Figure 3.3-13 Elements used for Volume-Weighted Average Temperatures in CCV and OSV Bolt Regions. 3.3-31
Figure 3.4-1 3-D Finite Element Model with Damage from Top-End Drop/Puncture 3.4-14
Figure 3.4-2 Thermal Contact Pairs in the HAC Model..... 3.4-15
Figure 3.4-3 Convection Boundary Conditions for HAC..... 3.4-16
Figure 3.4-4 Heat Transfer Coefficients for HAC Analyses (Fire)..... 3.4-17
Figure 3.4-5 Heat Transfer Coefficients for HAC Analyses (Post-Fire Cool-Down)..... 3.4-18
Figure 3.4-6 Application of the Heat Flux Boundary Conditions for HAC (1500 W)..... 3.4-19
Figure 3.4-7 Polyurethane Elements Exceeding 500°F at the End of the 30-Minute Fire 3.4-20
Figure 3.4-8 CCV O-rings and Inner Surface Temperature Time-Histories for HAC (200 W) 3.4-21
Figure 3.4-9 CCV O-ring and Inner Surface Temperature Time-Histories for HAC (1500 W) 3.4-21
Figure 3.4-10 HAC Transient Analysis Temperature Contours (200 W) 3.4-22
Figure 3.4-11 HAC Transient Analysis Temperature Contours (1500 W) 3.4-23
Figure 3.4-12 CCV Lid Temperature Contours (1500 W) at t = 7.9 hours. 3.4-24
Figure 3.4-13 OSV Lid Temperature Contours (1500 W) at t = 3.4 hours. 3.4-24
Figure 3.5-1 Comparison of the NCT Temperatures of the CCV Base Plate..... 3.5-7
Figure 3.5-2 Comparison of the NCT Temperatures of the CCV Shell 3.5-7
Figure 3.5-3 Comparison of the NCT Temperatures of the CCV Flange 3.5-8
Figure 3.5-4 Comparison of the NCT Temperatures of the CCV Lid..... 3.5-8
Figure 3.5-5 Comparison of the NCT Temperatures of the OSV Base..... 3.5-9
Figure 3.5-6 Comparison of the NCT Temperatures of the OSV Lid 3.5-9
Figure 3.5-7 HAC Temperature Contours When CCV O-ring Reaches is Maximum Temperature 3.5-10
Figure 3.5-8 CCV O-ring Temperature Time-Histories for HAC (1500 W) 3.5-11
Figure 3.5-9 CCV Maximum Seal Temperatures during HAC. 3.5-12
Figure 3.5-10 Pre-Fire Steady-State Temperature Contours, 1500 W, [redacted] Side/Corner Foam. 3.5-13

List of Tables

Table 3.1-1 Packaging Thermal Configurations 3.1-5
Table 3.1-2 Temperature Limits of Packaging Components 3.1-5
Table 3.1-3 Summary of Packaging Temperatures for NCT 3.1-6
Table 3.1-4 Summary of Packaging Temperatures for HAC 3.1-6
Table 3.1-5 Summary of Maximum Pressures 3.1-6
Table 3.2-1 Thermal Properties of [redacted] Stainless Steel 3.2-2
Table 3.2-2 Thermal Properties of [redacted] Ductile Cast Iron 3.2-2
Table 3.2-3 Thermal Properties of [redacted] 3.2-3
Table 3.2-4 Thermal Properties of Dry Air at Standard Pressure 3.2-4
Table 3.2-5 Thermal Properties of Helium Gas at Standard Pressure 3.2-5
Table 3.3-1 Insolation Data 3.3-15
Table 3.3-2 Finite Element Model Real Constant Material Property IDs 3.3-16
Table 3.3-3 Typical [redacted] Values from the Open Literature 3.3-17
Table 3.3-4 [redacted] Values Used in the Thermal Evaluation 3.3-17
Table 3.3-5 [redacted] 3.3-18
Table 3.3-6 Nusselt Number Calculation Constants of a Cylinder in Cross Flow 3.3-18
Table 3.3-7 Summary of NCT Boundary Conditions for Upright Package 3.3-18
Table 3.3-8 Maximum Temperatures for NCT, TRU Waste 3.3-28
Table 3.3-9 Maximum Temperatures for NCT, Fuel Waste 3.3-29
Table 3.3-10 Summary of NCT Pressures 3.3-35
Table 3.4-1 Impact Limiter Foam Density Resulting from HAC Free Drop and Puncture 3.4-11
Table 3.4-2 Summary of HAC Boundary Conditions 3.4-12
Table 3.4-3 Packaging Maximum Temperatures for HAC 3.4-13
Table 3.4-4 Summary of HAC Pressures 3.4-13
Table 3.5-1 Maximum NCT Package Temperatures (110g vs 55g Drum) 3.5-6
Table 3.5-2 Maximum HAC Package Temperatures for Two CCV Positions 3.5-6

THIS PAGE INTENTIONALLY LEFT BLANK

3 THERMAL EVALUATION

This section summarizes the thermal evaluation of the OPTIMUS®-H package, Type B(U)F-96, designed to support fuel waste and TRU waste projects. The results of the thermal evaluation demonstrate that the packaging will remain within the applicable thermal limits, demonstrating the package's structural, containment and shielding integrity is not negatively affected during the Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) prescribed by 10 CFR 71. In addition, as discussed in Section 4.5.5.3.2, the thermal evaluation of a postulated combustion event from non-compliant TRU waste contents shows that the resulting maximum packaging temperatures remain lower than the respective packaging material temperature limits.

This page intentionally left blank.

3.1 Description of Thermal Design

The OPTIMUS®-H packaging, shown in Figure 1-1, consists of a Cask Containment Vessel (CCV) within an Outer Shield Vessel (OSV) equipped with an Impact Limiter System (ILS). An optional Shield Insert Assembly (SIA) may be used inside the CCV to provide supplemental shielding for some contents. Narrative descriptions of these components are provided in Section 3.1.1.

3.1.1 Design Features

Containment of the radioactive contents is provided by the CCV. Impact and thermal protection for the CCV is provided by the OSV and ILS. All details and relevant dimensions of the packaging components are provided in the Licensing Drawings in Appendix 1.3.3.

CCV Design Features

The CCV is the innermost vessel of the packaging, that serves as the primary containment boundary of the package. [redacted] The CCV lid is machined to include operating and containment features, such as a port for evacuation and backfill of the cavity with inert gas and O-ring grooves to provide a leaktight seal. [redacted]

OSV Design Features

The OSV, which consists of a body and lid, [redacted] serves as the primary shielding component of the package, and provides impact and thermal protection to the CCV. [redacted]

ILS Design Features

The ILS is comprised of two impact limiters [redacted] to provide impact and thermal protection for the package and protect the OSV lid. The

[redacted] The structural evaluation presented in Chapter 2 shows the impact limiters remain attached to the OSV following the HAC free drop and HAC puncture tests. [redacted]

3.1.2 Content's Decay Heat

The contents are divided into three groups with respect to the allowable decay heat. Section 1.2.2.1 outlines the requirements for TRU waste contents, limited to 200 W total decay heat with helium cavity fill gas or 50 W total decay heat with air in the CCV cavity. Section 1.2.2.2 outlines the requirements for irradiated fuel waste contents, limited to 1,500 W total decay heat with helium cavity fill gas. The allowable shipping configuration of the package is restricted based on the content type being transported. The contents with the associated permissible decay heats and shipping configurations are shown in Table 3.1-1.

3.1.3 Summary Tables of Temperatures

Thermal design criteria are specified for the packaging components that are significant to the shielding and containment design. All operating temperature limits are based on the performance requirements of the individual packaging components. These operating temperature limits of the package components that are significant to the shielding and containment design are outlined in Table 3.1-2, including the temperature requirements for maximum temperature on the package accessible surfaces that are specified in 10CFR71.43(g). Note that temperature limit is not required for the waste contents.

Normal Conditions of Transport

Per the requirements of 10 CFR 71.71(c)(1), the package with TRU or fuel waste is evaluated for NCT, as presented in Section 3.3. Specifically, steady-state thermal analyses are performed simulating exposure of the package to a 100°F (38°C) temperature with insolation as specified in Table 3.3-1. The results of the analyses are presented in Section 3.3.1. The temperatures of several key package components are summarized and compared with their allowable temperatures in Table 3.1-3.

As presented in Table 3.1-3, the package components remain below their allowable temperatures for NCT. Therefore, when exposed to NCT, the structural, containment, and shielding performances of the package will not be adversely affected by the temperatures experienced under these conditions.

The package containing IFW (LEU or CANDU fuel waste) must be shipped under exclusive use controls. However, the package with ILW contents may be shipped under exclusive use controls or on a nonexclusive use conveyance. In accordance with 10 CFR 71.43(g) the maximum temperature on the accessible surface of the package in still air at 38°C (100°F) and in the shade is limited to 122°F (50°C) for nonexclusive use and 185°F (85°C) for exclusive use. As shown in Table 3.3-8, the maximum temperature of the accessible surface of a package with ILW contents when exposed to an ambient temperature of 100°F in still air and shade is 114°F (45°C), below the 122°F (50°C) temperature limit for nonexclusive use. As shown in Table 3.3-9, the maximum temperature of the accessible surface of the package with IFW contents, when exposed to an ambient temperature of 100°F in still air and shade, is 177°F (80°F), below the 185°F (85°C) temperature limit for exclusive use. Therefore, the temperature limits of 10 CFR 71.43(g) for nonexclusive and exclusive use are satisfied for the respective contents.

Hypothetical Accident Conditions

Per the requirements of 10 CFR 71.73(c)(4), the package with TRU or fuel waste is evaluated for HAC, as presented in Section 3.4. The results of the analyses are presented in Section 3.4.3. The temperatures of several key package components are summarized and compared to their allowable temperatures in Table 3.1-4. The polyurethane foam is not required to survive the HAC fire; therefore, it is not included in the summary. The impact limiter shells/plates are only required to maintain confinement of the polyurethane foam; therefore, they are only required to remain below their respective melting temperatures during HAC.

As presented in Table 3.1-4, the package components remain below their allowable temperatures for HAC. Therefore, when exposed to HAC, the structural, containment, and shielding performance of the package will not be adversely affected by the temperatures experienced under these conditions.

3.1.4 Summary Table of Maximum Pressures

The summary of maximum internal pressures in the CCV for NCT and HAC, calculated as described in Sections 3.3.2 and 3.4.3.2, respectively, is provided in Table 3.1-5. The maximum calculated internal pressure loads under NCT and HAC are 15.3 psi (105 kPa) gauge and 70.1 psi (483 kPa) gauge, respectively. The Maximum Normal Operating Pressure (MNOP) of the

package is conservatively set to 100 psi (690 kPa) gauge. In addition, a bounding internal pressure load of 225 psi (1,551 kPa) gauge is conservatively used for the structural evaluation of the CCV presented in Chapter 2.

Table 3.1-1 - Packaging Thermal Configurations

[redacted]

Table 3.1-2 - Temperature Limits of Packaging Components

[redacted]

Table 3.1-3 - Summary of Packaging Temperatures for NCT

[redacted]

Table 3.1-4 - Summary of Packaging Temperatures for HAC

[redacted]

Table 3.1-5 - Summary of Maximum Pressures

[redacted]

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

The packaging is fabricated primarily from [redacted] stainless steel, DCI, and polyurethane foam materials. Table 3.2-1 and Table 3.2-2 provide the thermal properties for stainless steel and DCI that are used for the CCV and OSV, respectively. The properties for these polyurethane foams are provided in the manufacturer's catalog. These properties are therefore subject to verification upon procurement or otherwise determined to be bounding of the as-built properties. The properties for the polyurethane foam are presented in Table 3.2-3. The thermal properties for dry air are presented in Table 3.2-4. The thermal properties for helium are presented in Table 3.2-5.

3.2.2 Component Specifications

The package components that are significant to the containment and shielding design are primarily SS and DCI. The temperature limits of these components are summarized in Table 3.1-2. Otherwise, component maximum temperature limits are defined as the melting temperature of the material of construction. The minimum temperature limit for all components is -40°C (-40°F).

The [redacted] O-ring seal material used as the containment boundary O-ring seals for the CCV lid and port cover has a continuous operating temperature range of -40°F (-40°C) to 400°F (204°C) [3.1].

Table 3.2-1 - Thermal Properties of [redacted] Stainless Steel

[redacted]

Table 3.2-2 - Thermal Properties of [redacted] Cast Iron

[redacted]

Table 3.2-3 - Thermal Properties of [redacted]

[redacted]

Table 3.2-4 - Thermal Properties of Dry Air at Standard Pressure

Temp (°F)	Thermal Conductivity, k (E-3, Btu/h·in·°F)	Kinematic Viscosity, v (E+2, in^2/h)	Thermal Diffusivity, α (E+2, in^2/h)	Specific Heat, c_p (Btu/lbm·°F)	Prandtl Number, P_r	Density, ρ (E-5, lb/in^3)
-99	0.872	0.424	0.575	0.2405	0.737	6.31
-9	1.074	0.638	0.887	0.2403	0.720	5.04
81	1.266	0.887	1.26	0.2405	0.707	4.20
171	1.445	1.17	1.67	0.2410	0.700	3.59
261	1.627	1.47	2.14	0.2422	0.690	3.15
351	1.796	1.81	2.63	0.2439	0.686	2.80
441	1.960	2.16	3.16	0.2460	0.684	2.52
531	2.114	2.54	3.72	0.2484	0.683	2.29
621	2.258	2.94	4.29	0.2510	0.685	2.10
711	2.393	3.36	4.87	0.2539	0.690	1.93
801	2.523	3.80	5.47	0.2568	0.695	1.80
891	2.643	4.26	6.08	0.2596	0.702	1.68
981	2.759	4.74	6.70	0.2625	0.709	1.57
1071	2.870	5.23	7.31	0.2651	0.716	1.48
1161	2.985	5.74	7.98	0.2678	0.720	1.40
1251	3.096	6.26	8.65	0.2701	0.723	1.32
1341	3.212	6.80	9.37	0.2725	0.726	1.26
1521	3.443	7.91	10.9	0.2768	0.728	1.14

Table 3.2-5 - Thermal Properties of Helium Gas at Standard Pressure

Temperature (°F)	Thermal Conductivity, k (E-3, Btu/h·in·°F)	Kinematic Viscosity, v (E+2, in^2/h)	Thermal Diffusivity, α (E+2, in^2/h)	Prandtl Number, P_r	Density, ρ (E-6, lb/in^3)
-63	5.93	4.03	5.97	0.675	8.006
9	6.60	5.36	7.87	0.682	6.774
81	7.32	6.81	10.04	0.680	5.871
261	9.00	11.10	16.46	0.675	4.404
441	10.59	16.18	24.22	0.668	3.524
801	13.39	28.01	42.85	0.654	2.518
1341	17.05	51.00	78.12	0.654	1.763
1472	17.79	57.52	88.32	0.654	1.647

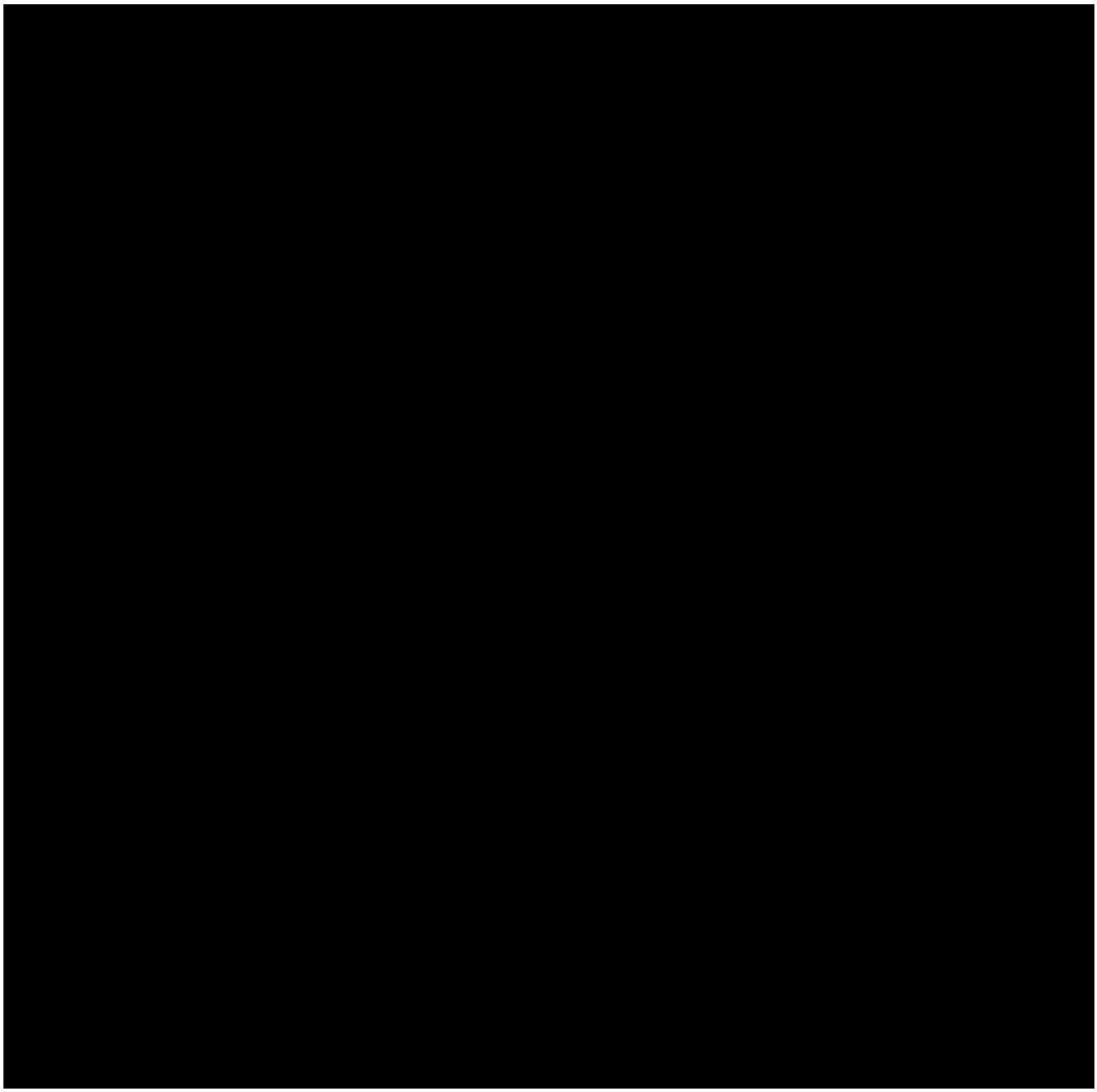
References: [3.7] All Properties: Table A.4, Page 997.
Notes: Specific heat is 1.24 Btu/lbm·°F for all temperatures.

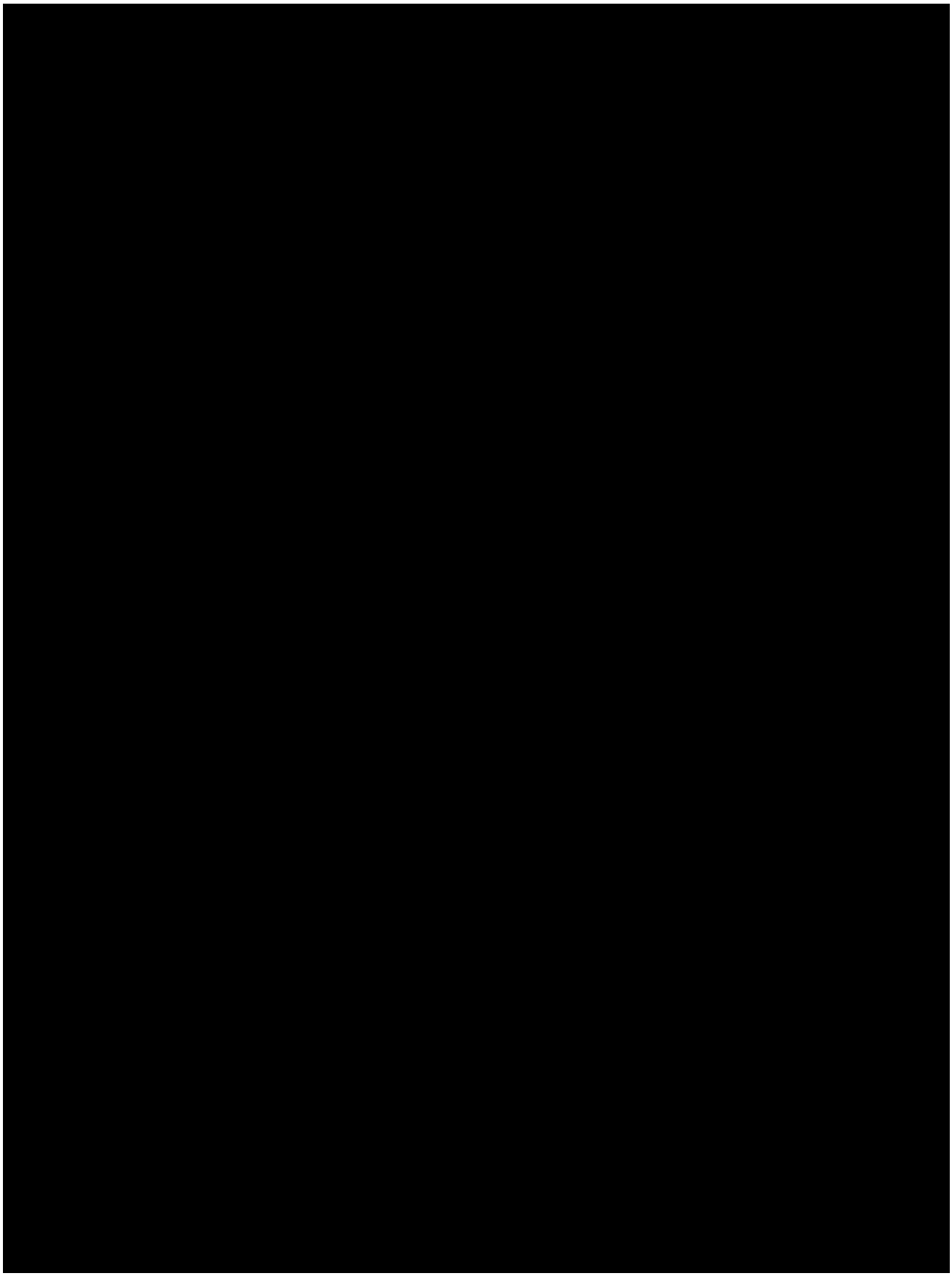
This page intentionally left blank.

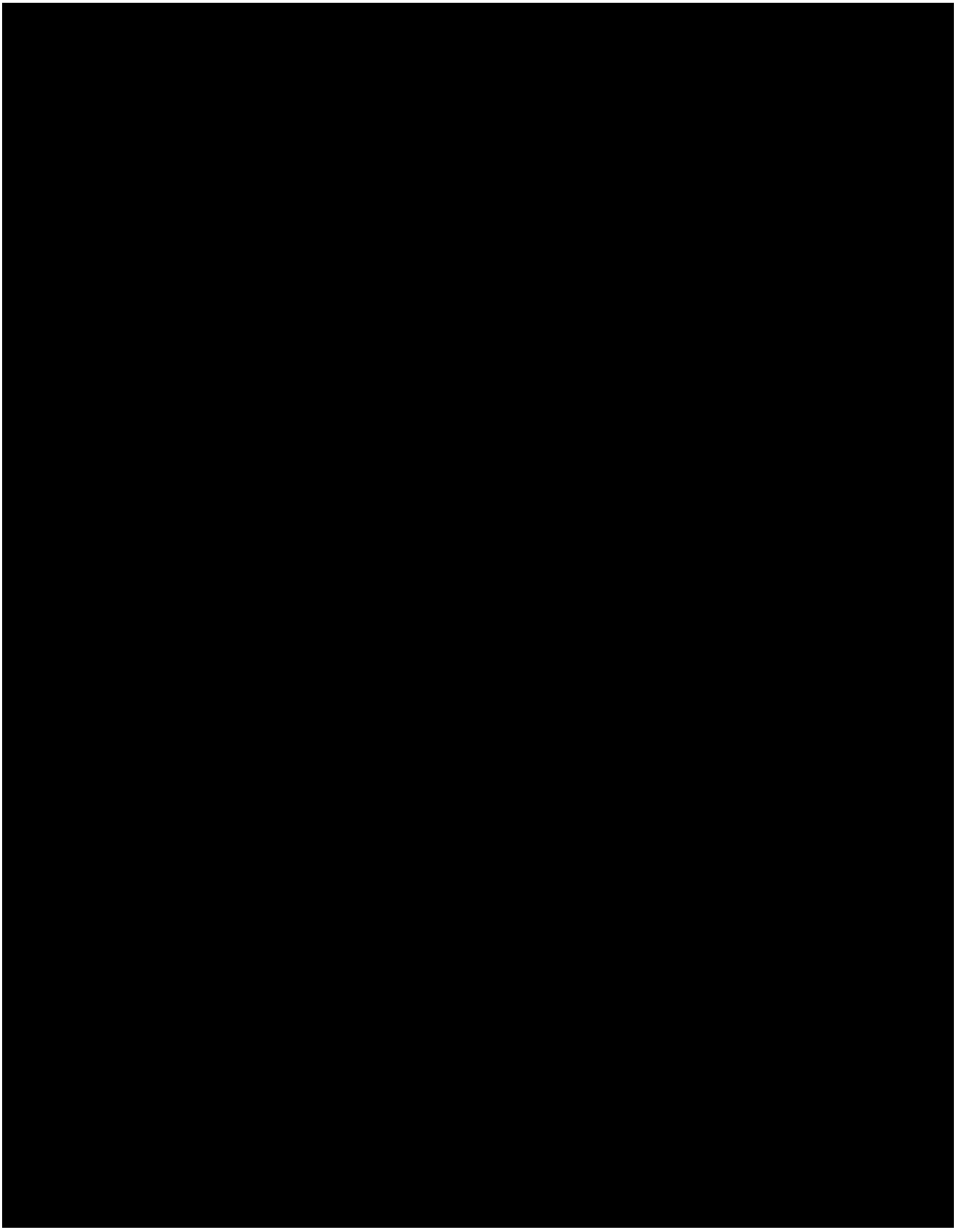
3.3 Thermal Evaluation Under Normal Conditions of Transport

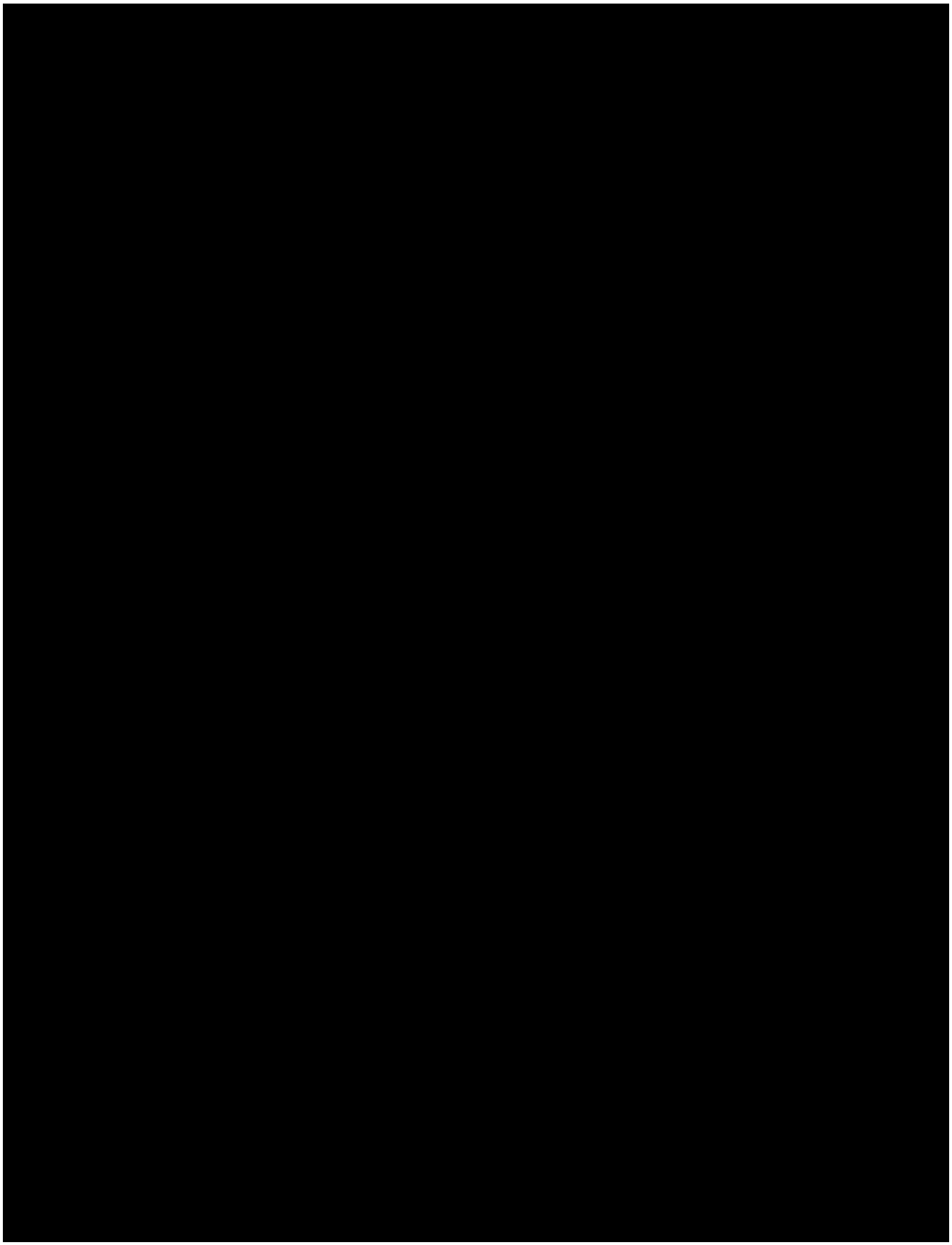
This section describes the thermal evaluation of the package under normal conditions of transport (NCT). The evaluation is conducted using analytical methods in accordance with 10 CFR 71 and Regulatory Guide 7.8 for the applicable NCT thermal loads. The results are compared with the allowable limits of temperature and pressure for the package components.

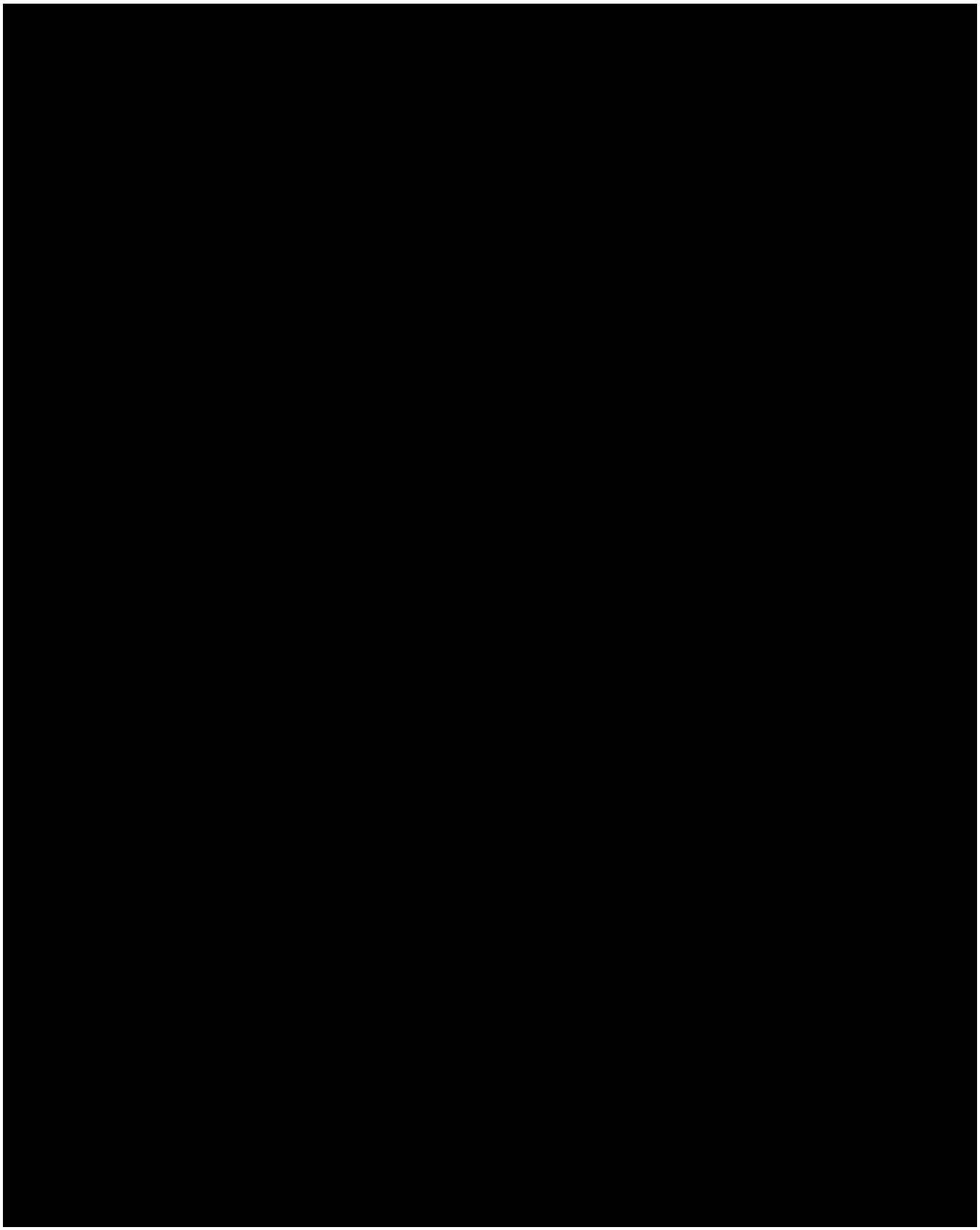
Analytical Approach

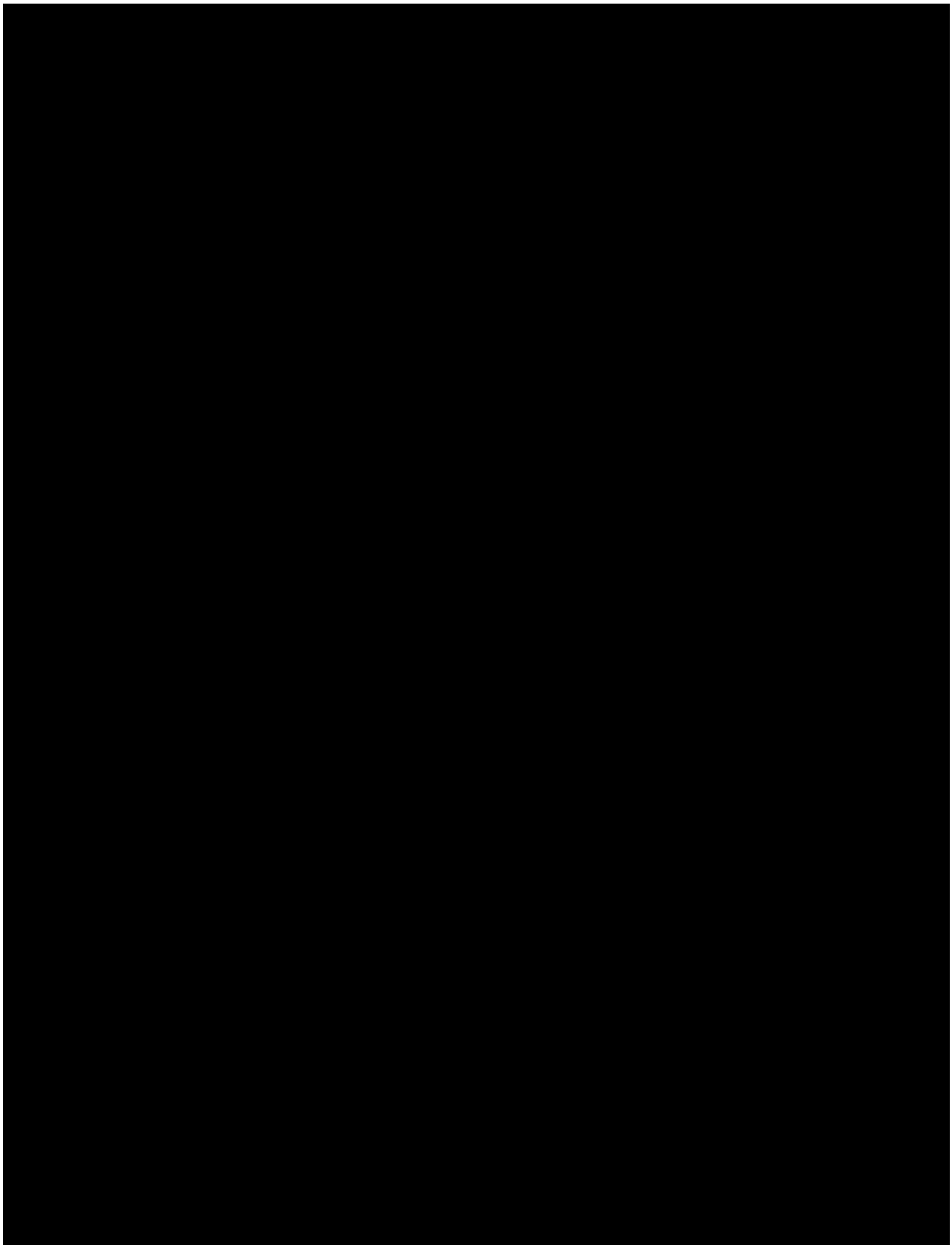


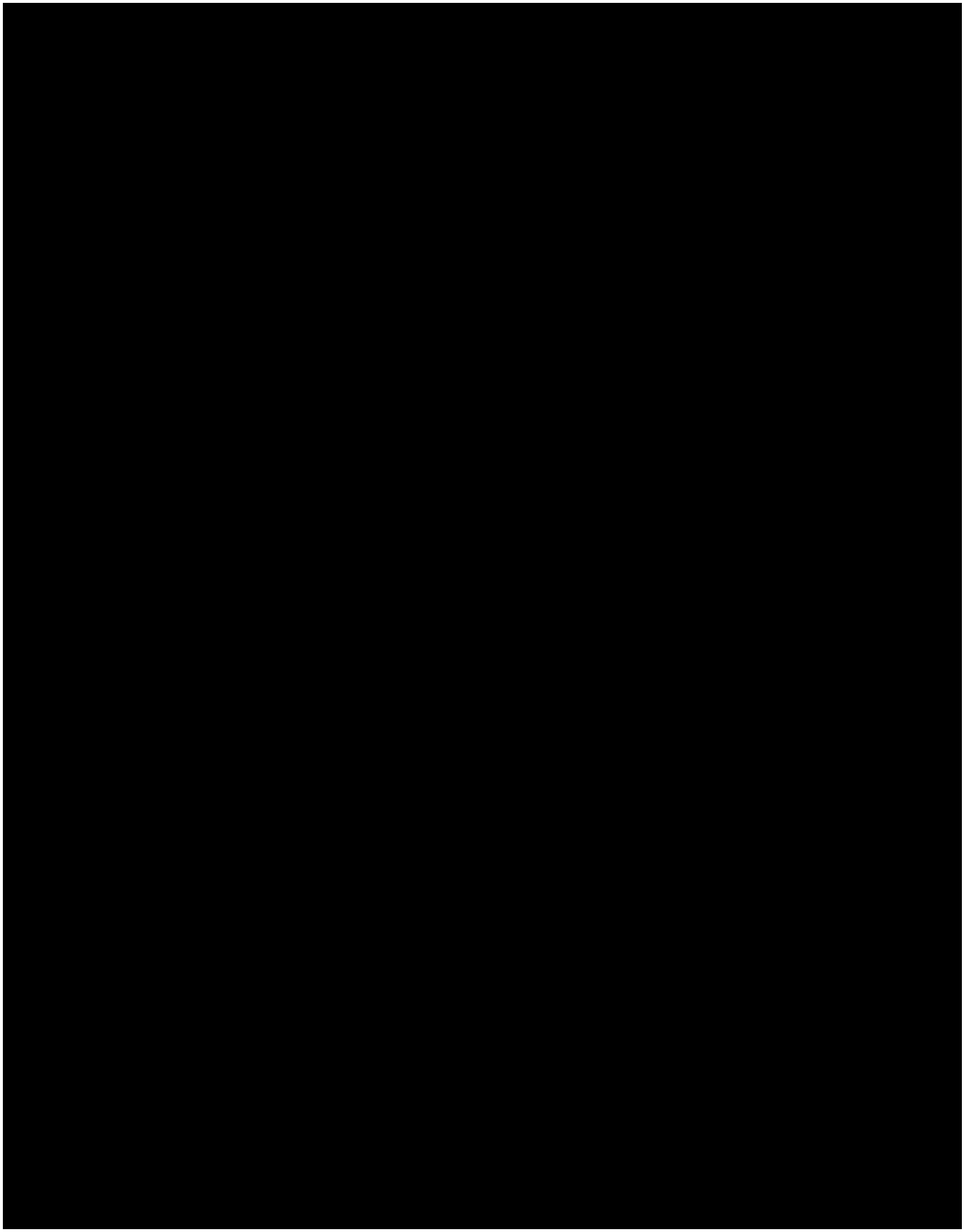


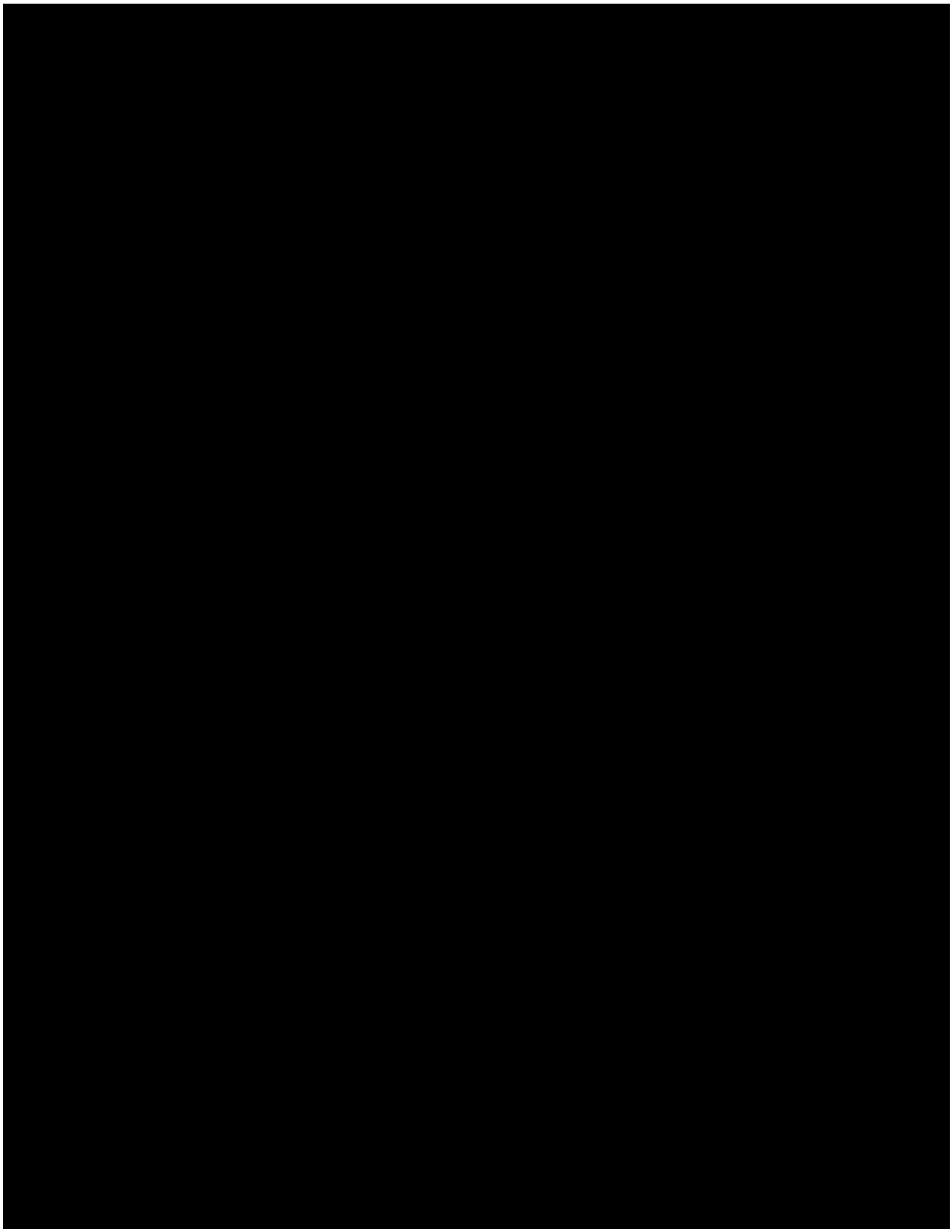


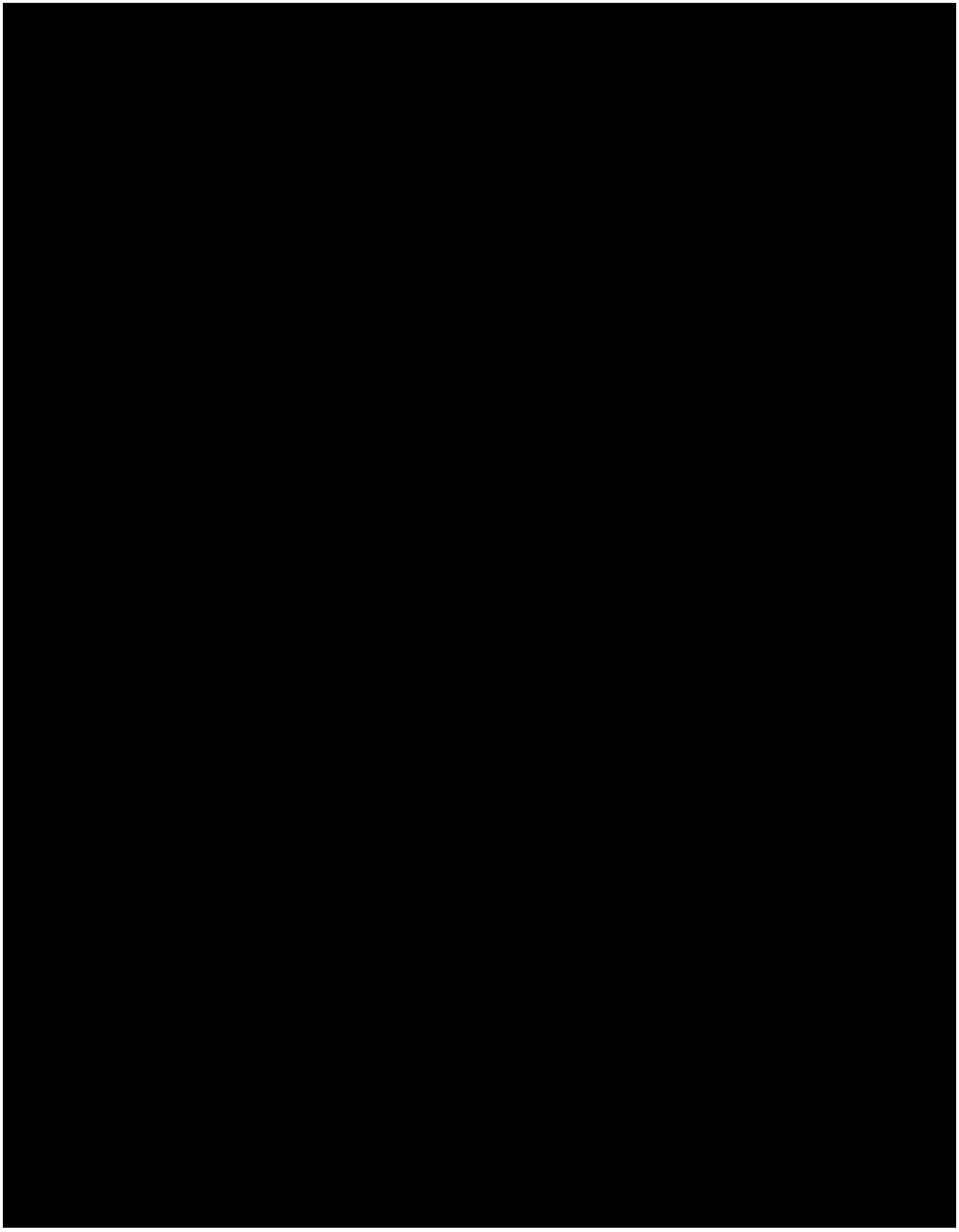


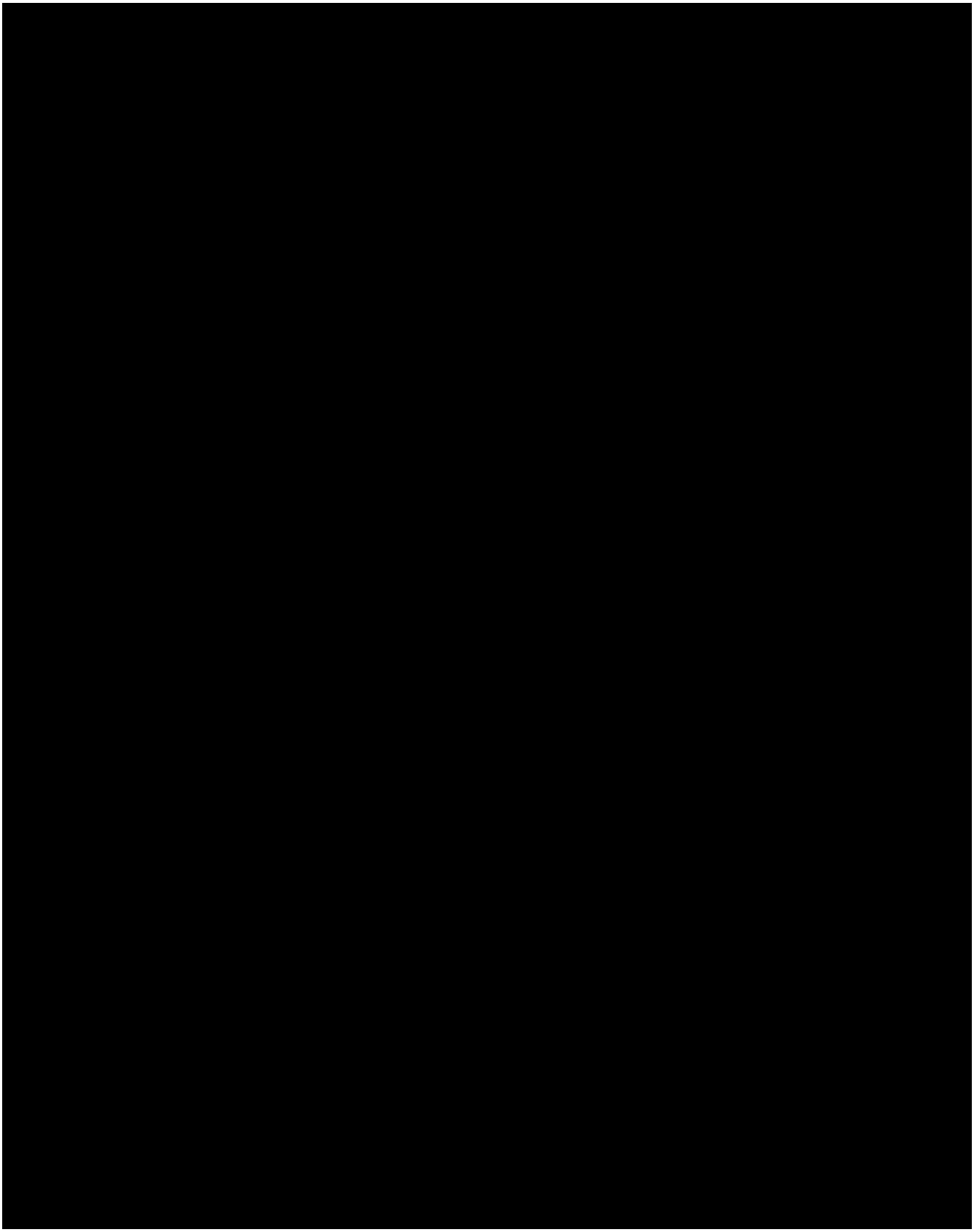


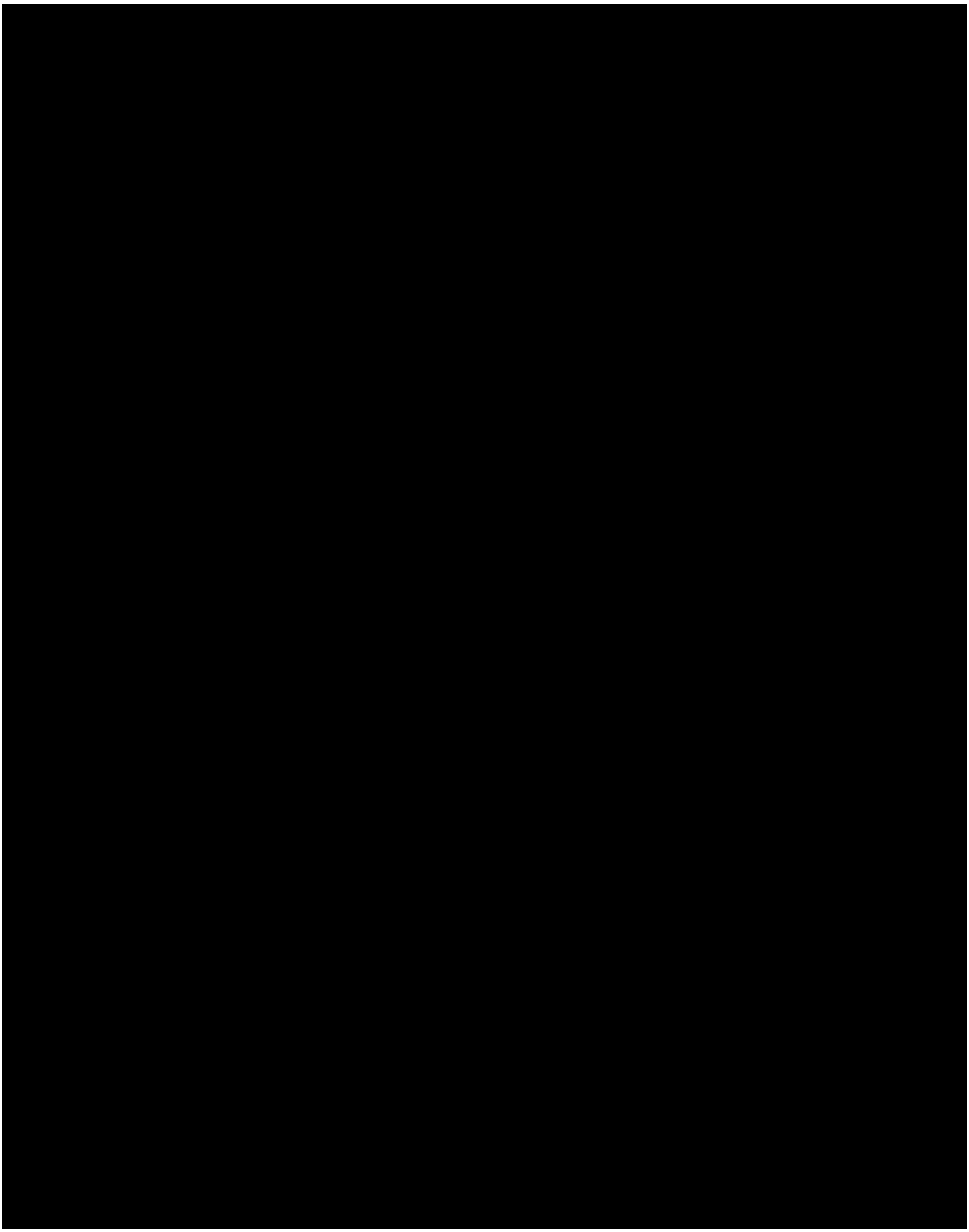


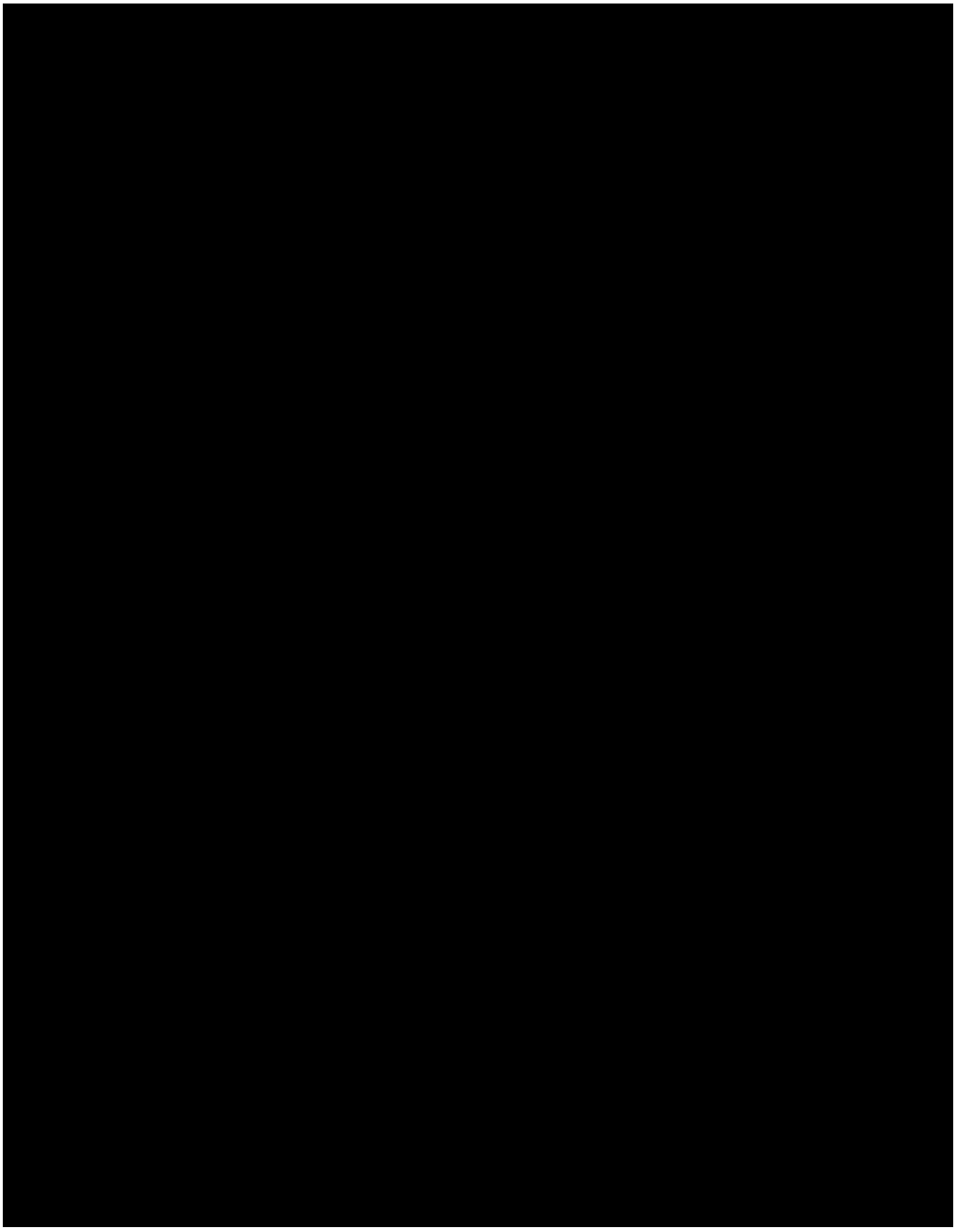












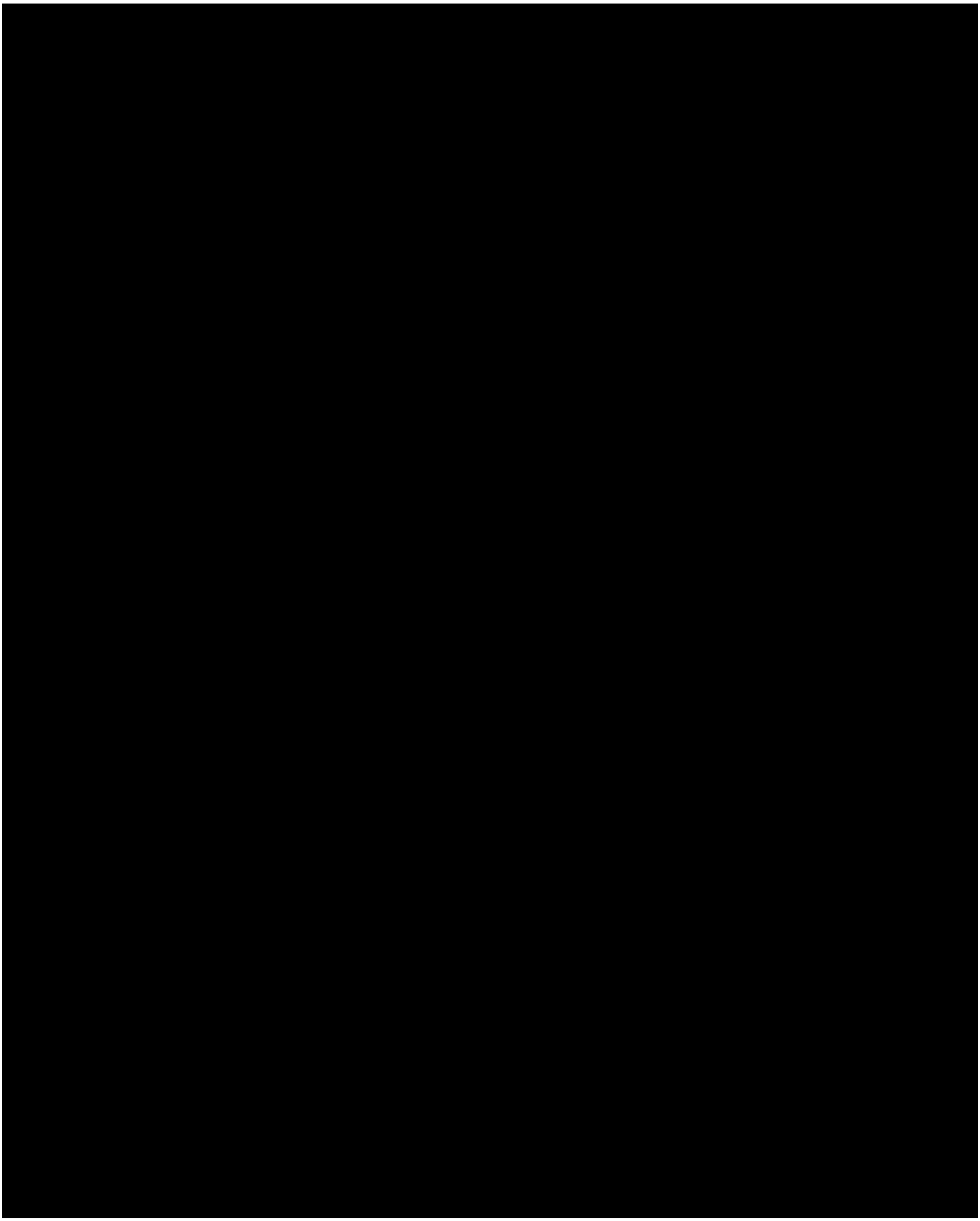


Table 3.3-1 - Insolation Data

Form and location of surface	Total insolation for a 12-hour period (g cal/cm²)
Flat surfaces transported horizontally;	
Base	None
Other surface	800
Flat surfaces not transported horizontally	200
Curved surfaces	400

Table 3.3-2 - [redacted]

[redacted]

Table 3.3-3 - Typical [redacted] Values from the Open Literature

[redacted]

Table 3.3-4 - [redacted] Values Used in the Thermal Evaluation

[redacted]

Table 3.3-5 - [redacted]

[redacted]

Table 3.3-6 - Nusselt Number Calculation Constants of a Cylinder in Cross Flow.

[redacted]

Table 3.3-7 - Summary of NCT Boundary Conditions for Upright Package

[redacted]

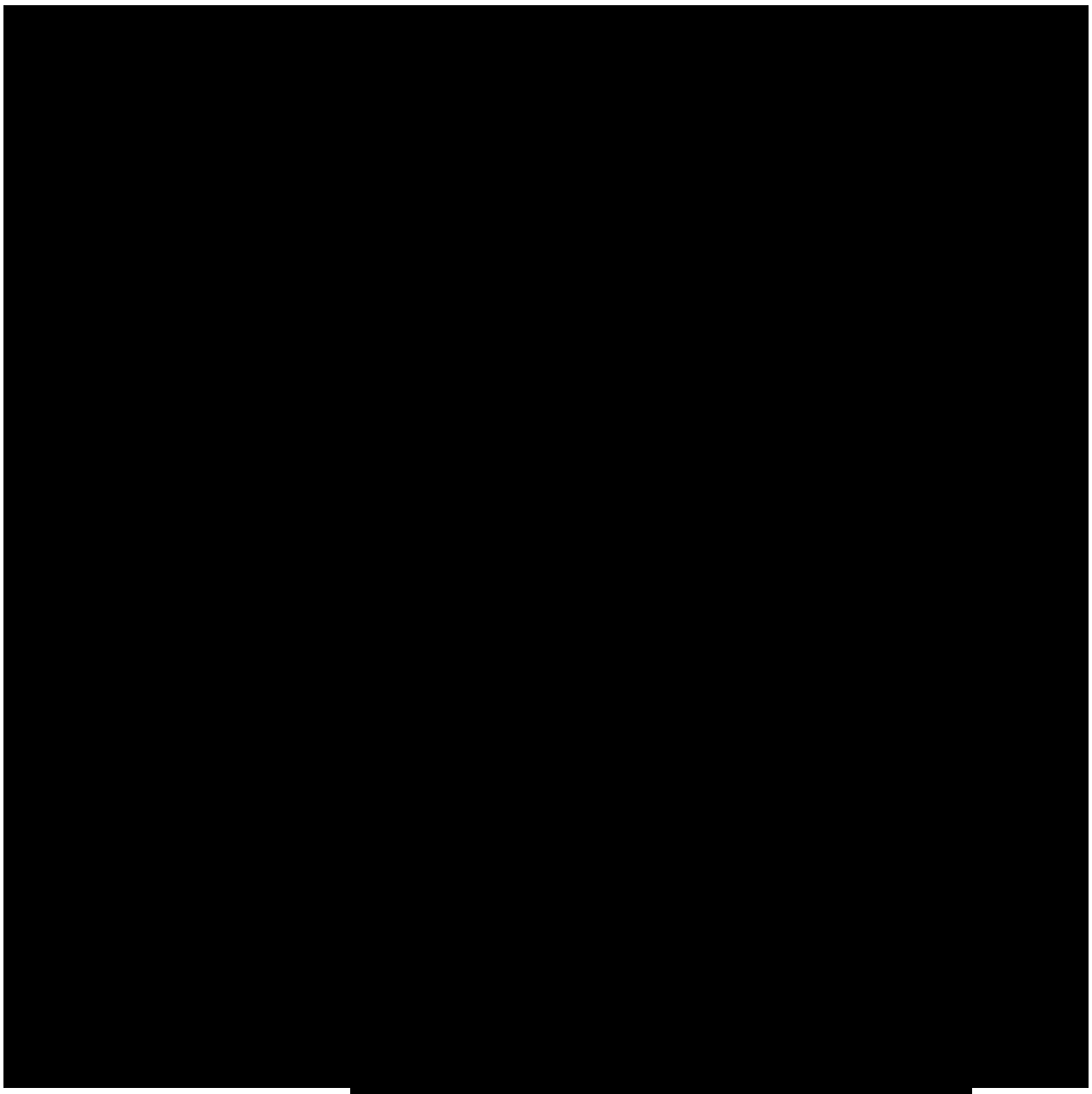


Figure 3.3-1 -

Figure 3.3-2 - Three-Dimensional Finite Element Model of Impact Limiters Shells
(Note: see Table 3.3-2 for Real Constant IDs)

Figure 3.3-3 - Exploded View of the CCV with Modeled TRU Waste in 110-Gallon Drum

Figure 3.3-4 - Exploded View of the CCV with Modeled Fuel Waste

Figure 3.3-5 - Thermal Contact Pairs in the NCT Model

Figure 3.3-6 - Application of Convection Boundary Conditions for NCT (and Shade)

Figure 3.3-7 - Heat Transfer Coefficients for General Standards (shade) and NCT

Figure 3.3-8 - Heat Flux Boundary Conditions for NCT (200W)

Figure 3.3-9 - Volumetric Heat Generation Boundary Conditions for NCT

3.3.1 Heat and Cold

Per the requirements of 10 CFR 71.71(c)(1), the packaging with TRU or fuel waste contents is evaluated for NCT. Specifically, steady-state thermal analyses are performed simulating exposure of the package to 100°F (38°C) ambient temperature with insolation as specified in Table 3.3-1. The results of the analyses are presented in this section. The temperatures of several key package components are summarized and compared with their allowable temperatures in Table 3.1-2.

As presented in Table 3.1-3, the package components remain below their allowable temperatures for NCT. Therefore, when exposed to NCT, the structural, containment, and shielding performance of the package will not be adversely affected by the temperatures experienced under these conditions.

Table 3.3-8 - Maximum Temperatures for NCT, TRU Waste

Table 3.3-9 - Maximum Temperatures for NCT, Fuel Waste

Figure 3.3-10 - NCT Steady-State Temperatures – Fuel Waste (1500 W, He)

Figure 3.3-11 - CCV Lid Temperatures, NCT, Fuel Waste, 1500 W Heat Flux

Figure 3.3-12 - OSV Lid Temperatures, NCT, Fuel Waste, 1500 W Heat Flux

Figure 3.3-13 - Elements used for Volume-Weighted Average Temperatures in CCV and OSV Bolt Regions.

3.3.2 Maximum Normal Operating Pressure

The maximum normal operating pressures are calculated by treating all gases in the CCV as ideal gases. The total pressure is calculated by determining the partial pressure contributions from temperature change, water vapor pressure and gas generation from radiolysis.

$$P_2 = P_g + P_V$$

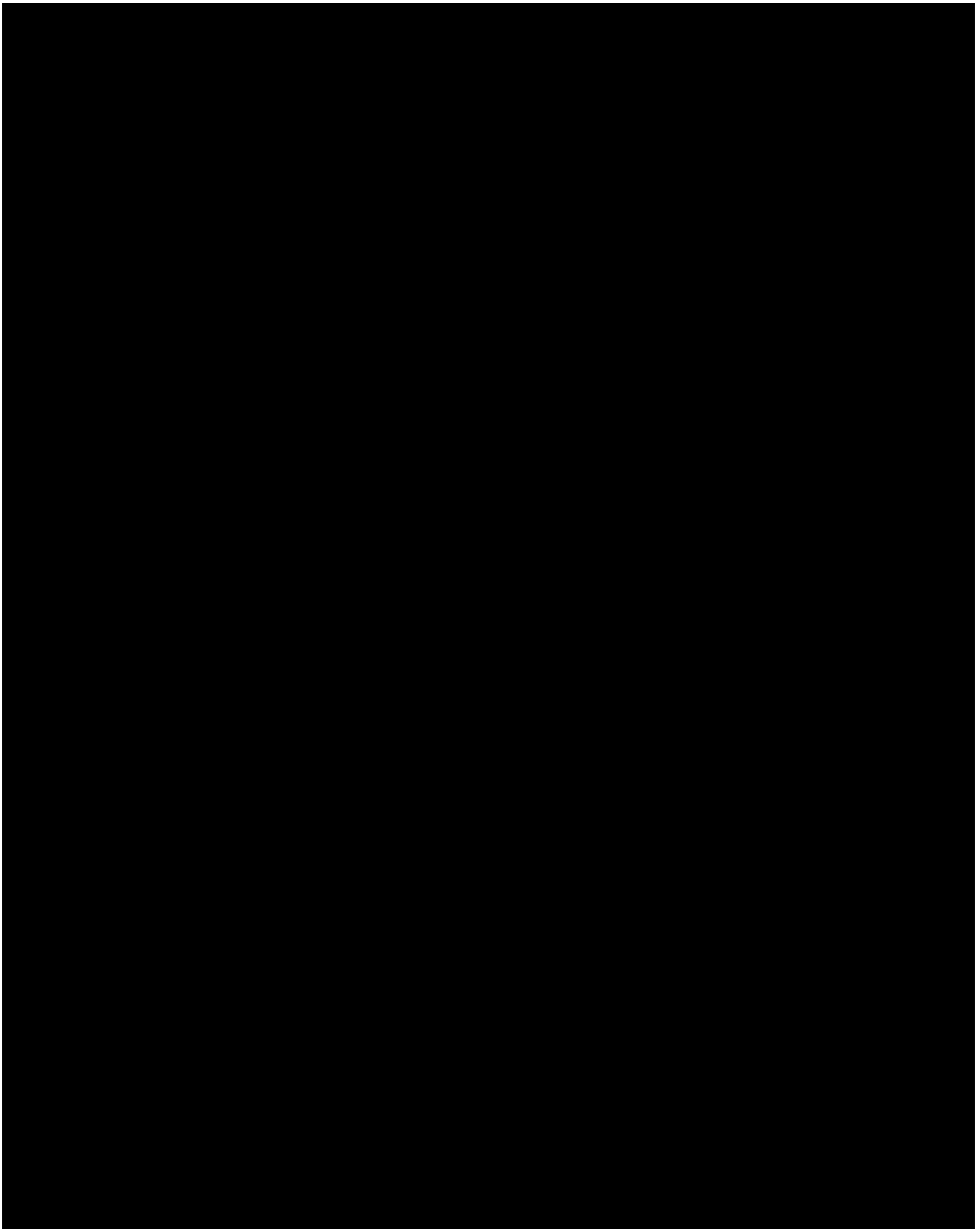
Where,

P_2 = Final pressure

P_g = Gas pressure due to the addition of radiolytic gases and heating of the CCV

P_V = Water vapor pressure

[redacted]



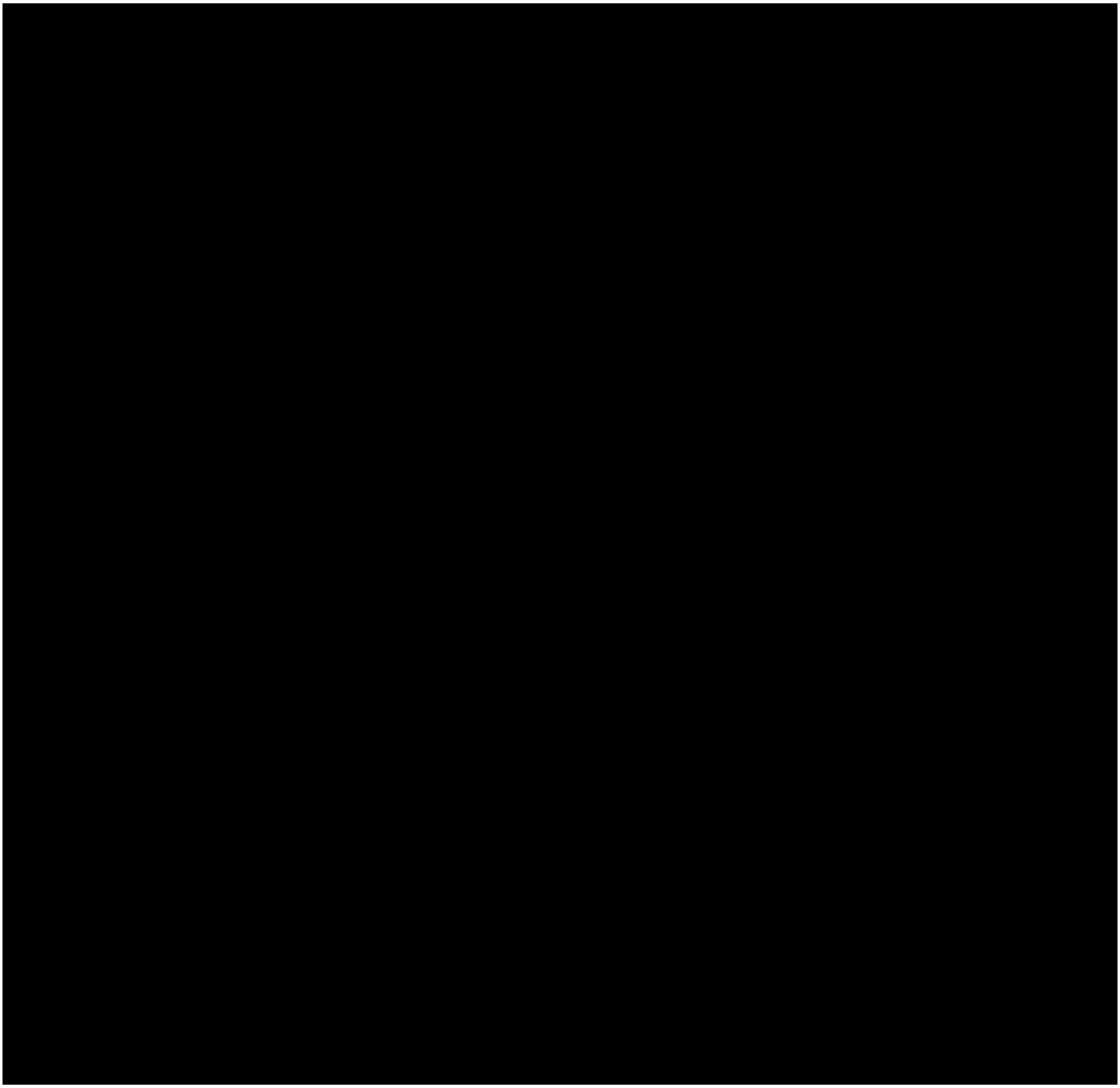


Table 3.3-10 - Summary of NCT Pressures

THIS PAGE INTENTIONALLY LEFT BLANK

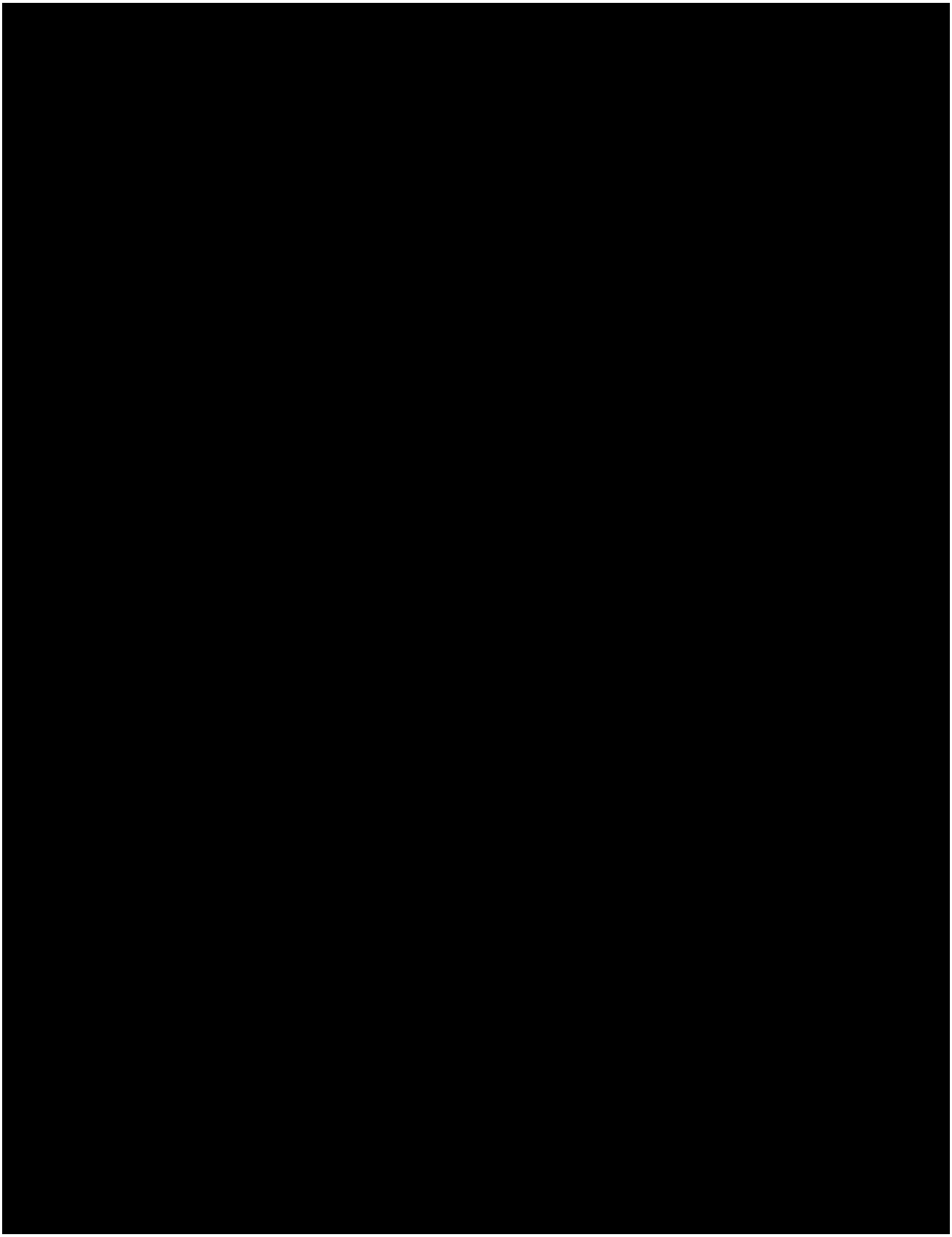
3.4 Thermal Evaluation Under Hypothetical Accident Conditions

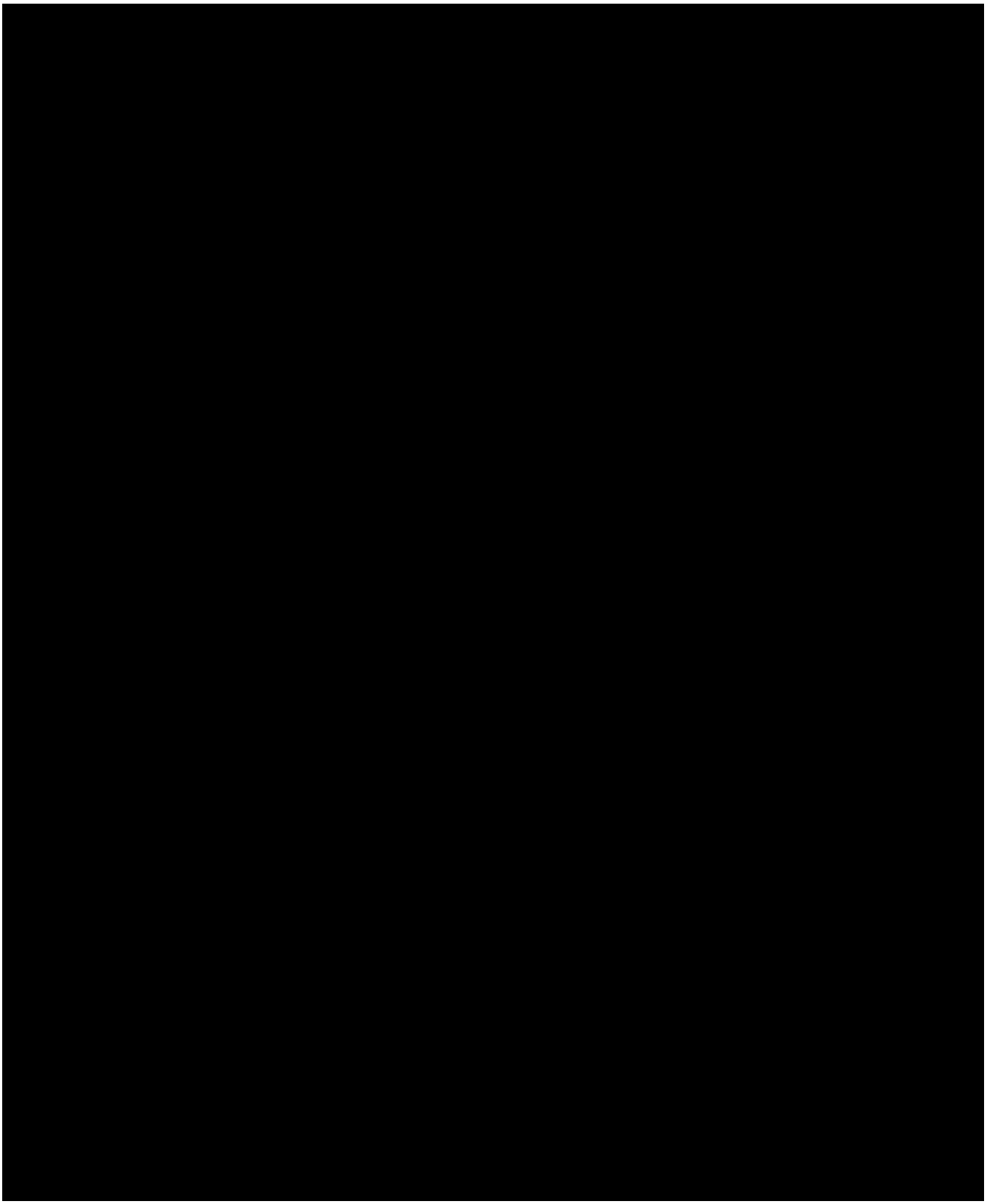
3.4.1 Initial Conditions

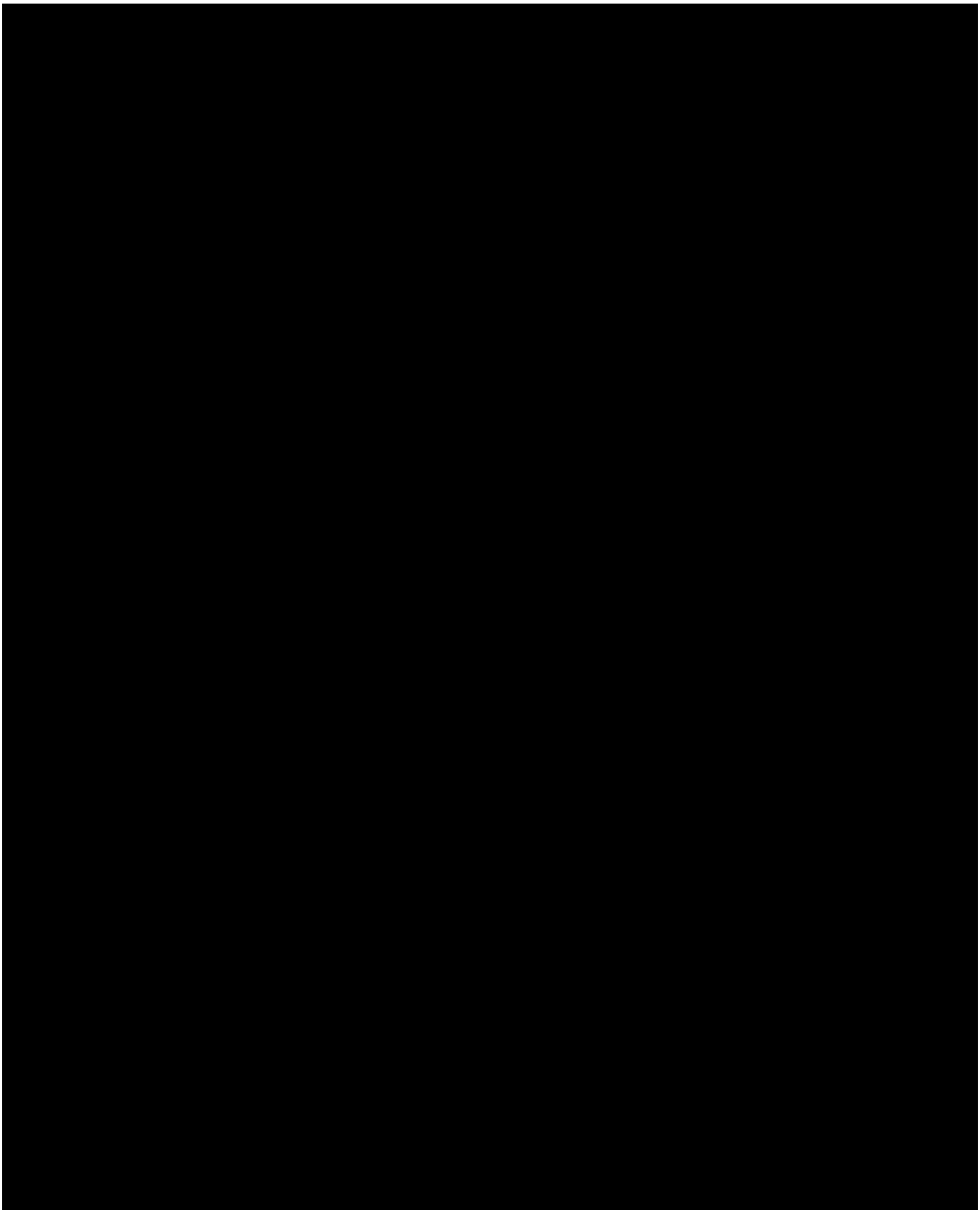
The thermal performance of the package with TRU or fuel waste for the HAC prescribed in 10 CFR 71.73(c)(4) is assessed by performing transient heat transfer analyses [redacted] analyze the package with content heat loads of 200 W (TRU waste) and 1500 W (fuel waste) for exposure to the 30-minute hypothetical accident fire.

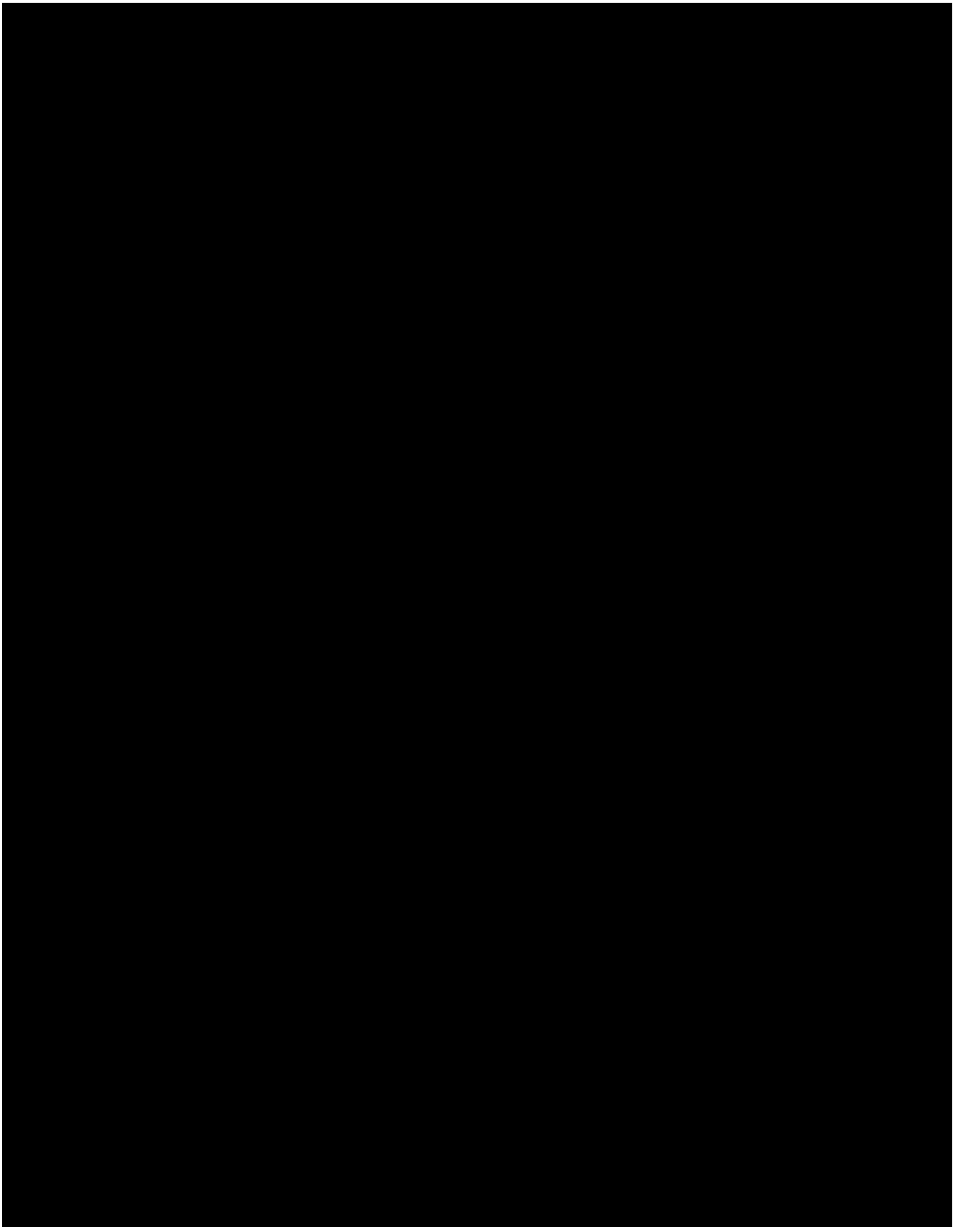
Drop Damage

[redacted]









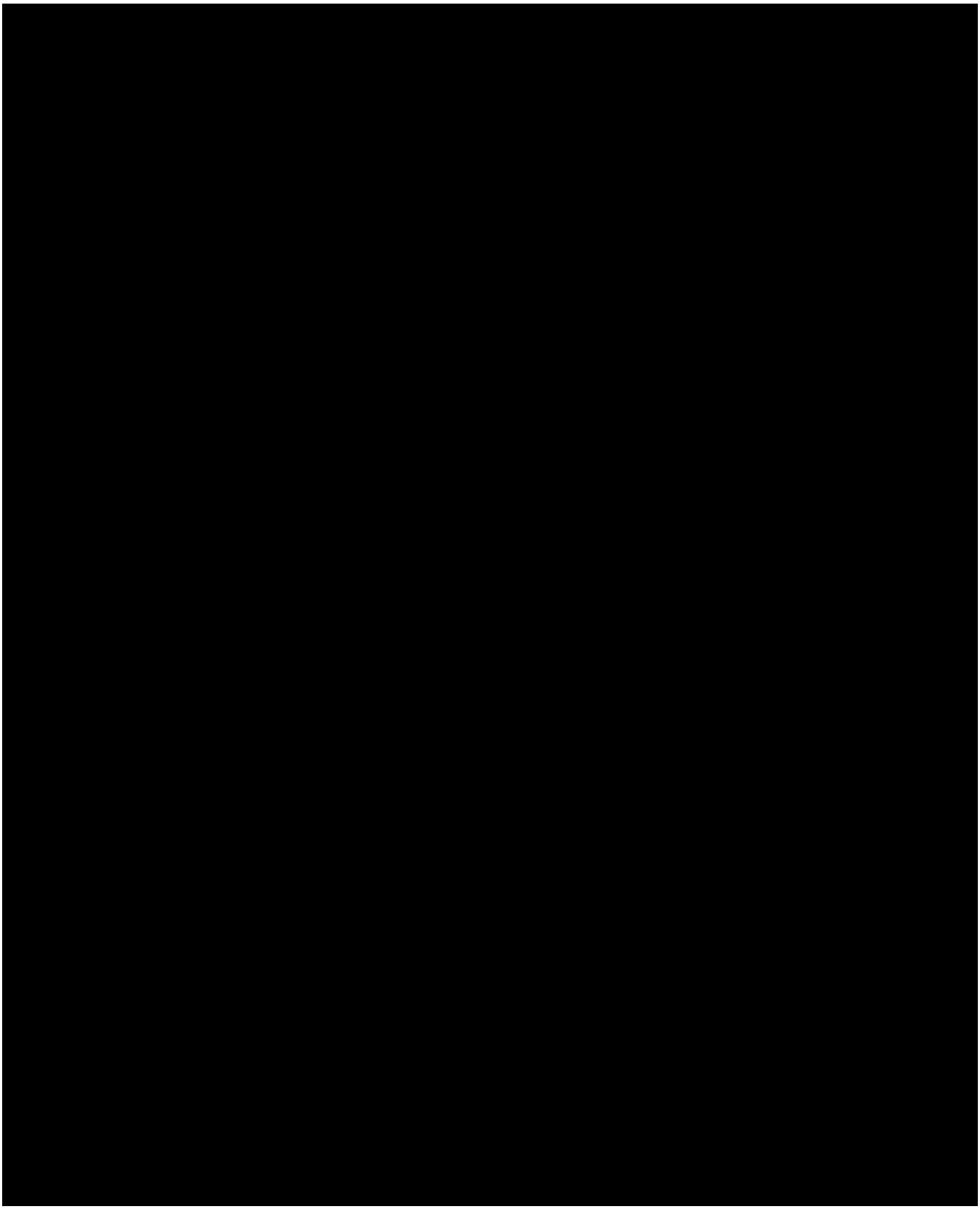
[redacted]

3.4.3 Maximum Temperatures and Pressure

3.4.3.1 Maximum HAC Temperatures Results

Per the requirements of 10 CFR 71.73(4), the package with TRU or fuel waste is evaluated for hypothetical accident conditions. [redacted]

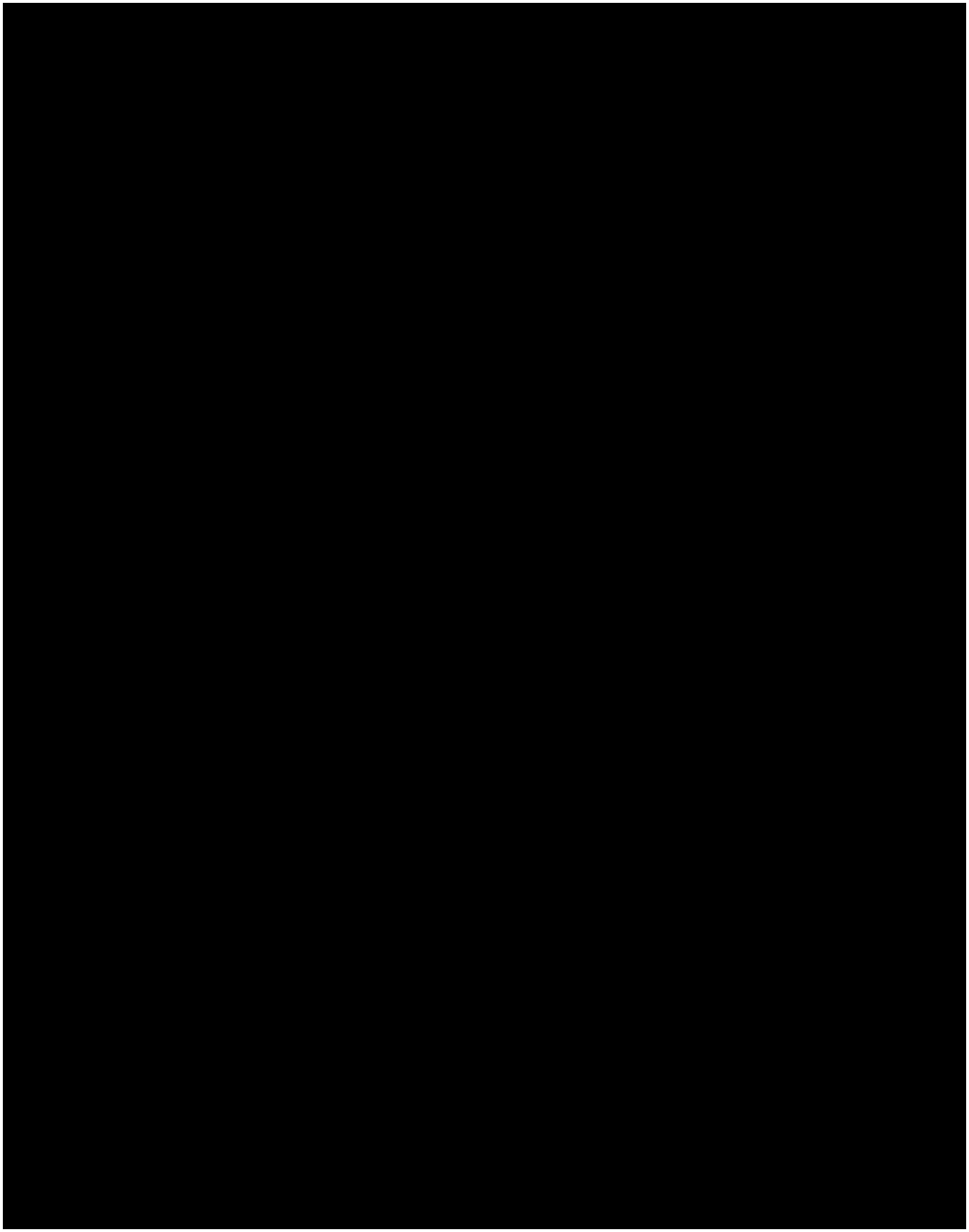
As presented in Table 3.1-4, the package components remain below their allowable temperatures for HAC. Therefore, when exposed to HAC, the package will maintain containment of its contents, and the structural performance of the package will not be adversely affected by the temperatures experienced under these conditions. No structural damage, breach of containment, or loss of shielding will not occur because of exposure to HAC.



[redacted]

3.4.3.2 Maximum HAC Pressure Results

The maximum pressures for HAC are determined using the same equations as for the MNOP calculations in Section 3.3.2 but considering the increased internal temperatures from a fire accident. [redacted]



3.4.5 Accident Conditions for Fissile Material Packages for Air Transport

The packaging is not presently authorized for air transport. Therefore, this section is not applicable.

Table 3.4-1 - Impact Limiter Foam Density Resulting from HAC Free Drop and Puncture

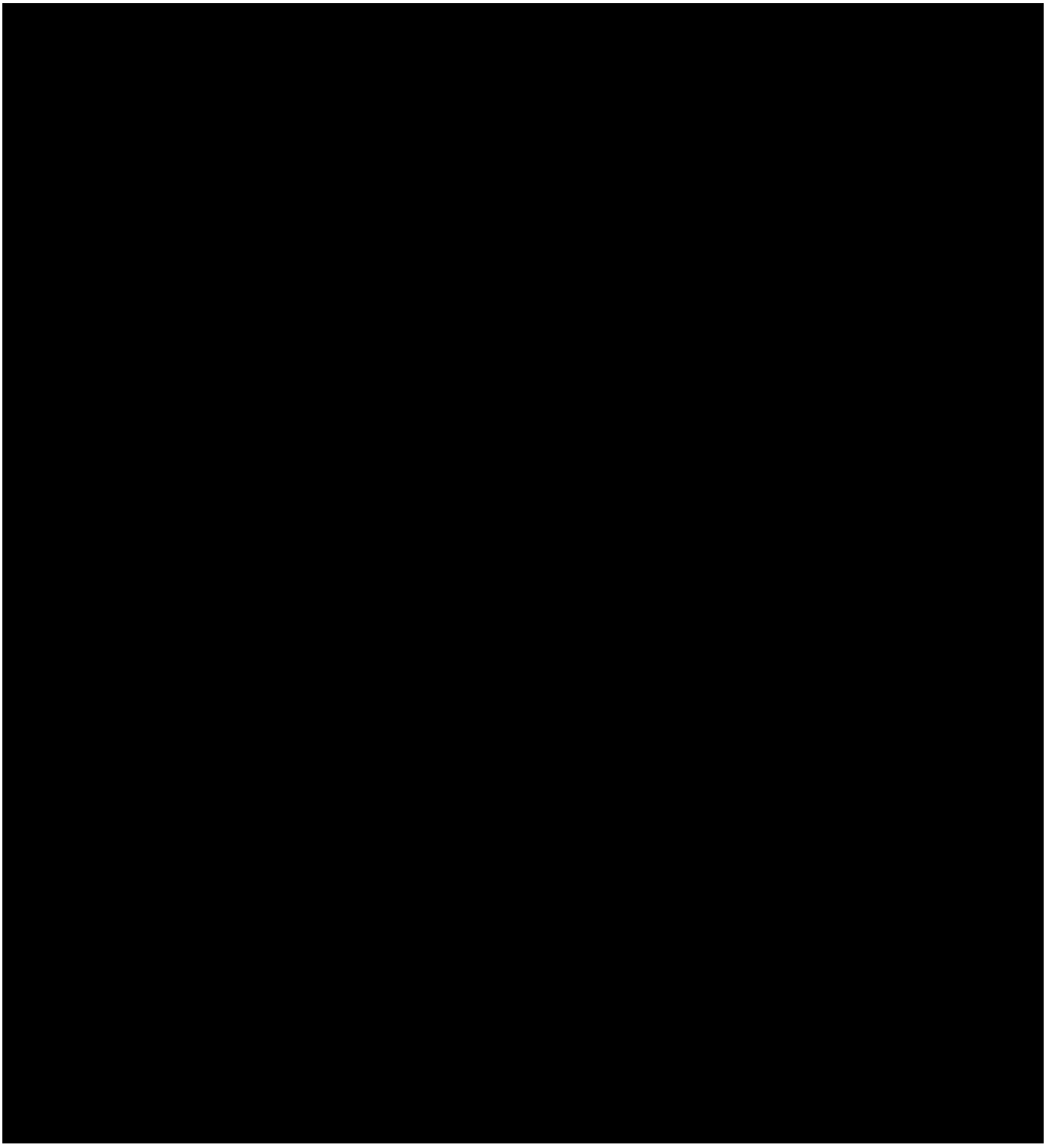


Table 3.4-2 - Summary of HAC Boundary Conditions

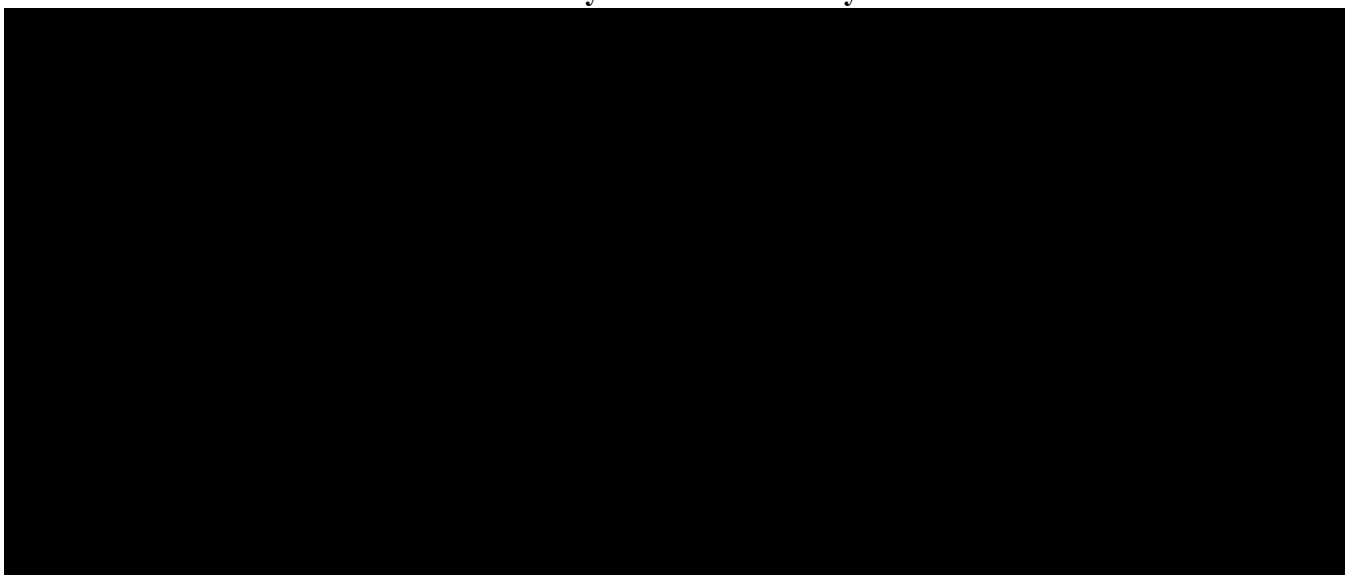


Table 3.4-3 - Packaging Maximum Temperatures for HAC

[redacted]

Table 3.4-4 - Summary of HAC Pressures

[redacted]

Figure 3.4-1 - 3-D Finite Element Model with Damage from Top-End Drop/Puncture
(Note: see Table 3.3-2 for Real Constant IDs)

Figure 3.4-2 - Thermal Contact Pairs in the HAC Model

Figure 3.4-3 - Convection Boundary Conditions for HAC

Figure 3.4-4 - Heat Transfer Coefficients for HAC Analyses (Fire)

Figure 3.4-5 - Heat Transfer Coefficients for HAC Analyses (Post-Fire Cool-Down)

Figure 3.4-6 - Application of the Heat Flux Boundary Conditions for HAC (1500 W)

Figure 3.4-7 - Polyurethane Elements Exceeding 500°F at the End of the 30-Minute Fire

Figure 3.4-8 - CCV O-rings and Inner Surface Temperature Histories for HAC (200 W)

Figure 3.4-9 - CCV O-ring and Inner Surface Temperature Time-Histories for HAC (1500 W)

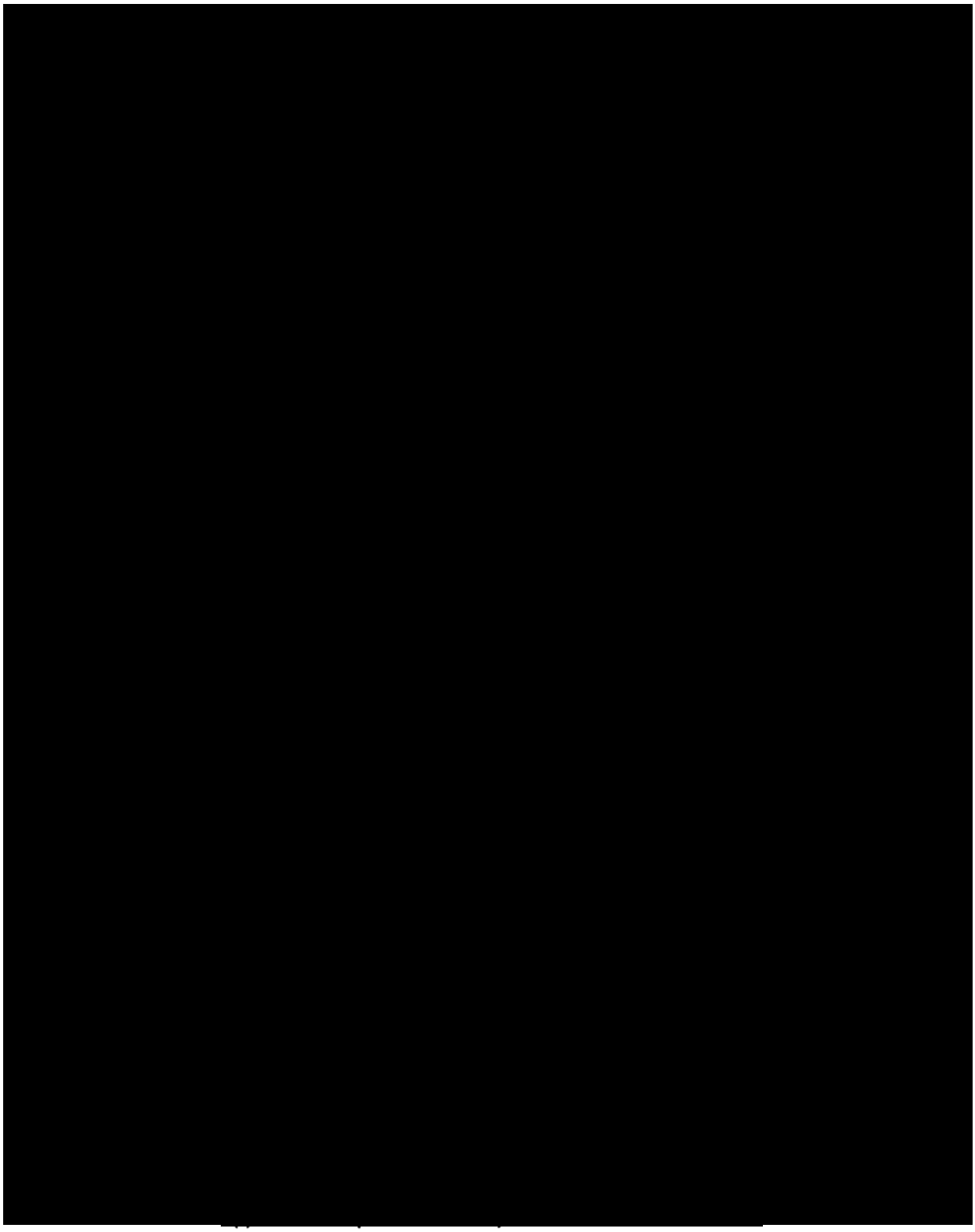


Figure 3.4-10 - HAC Transient Analysis Temperature Contours (200 W)

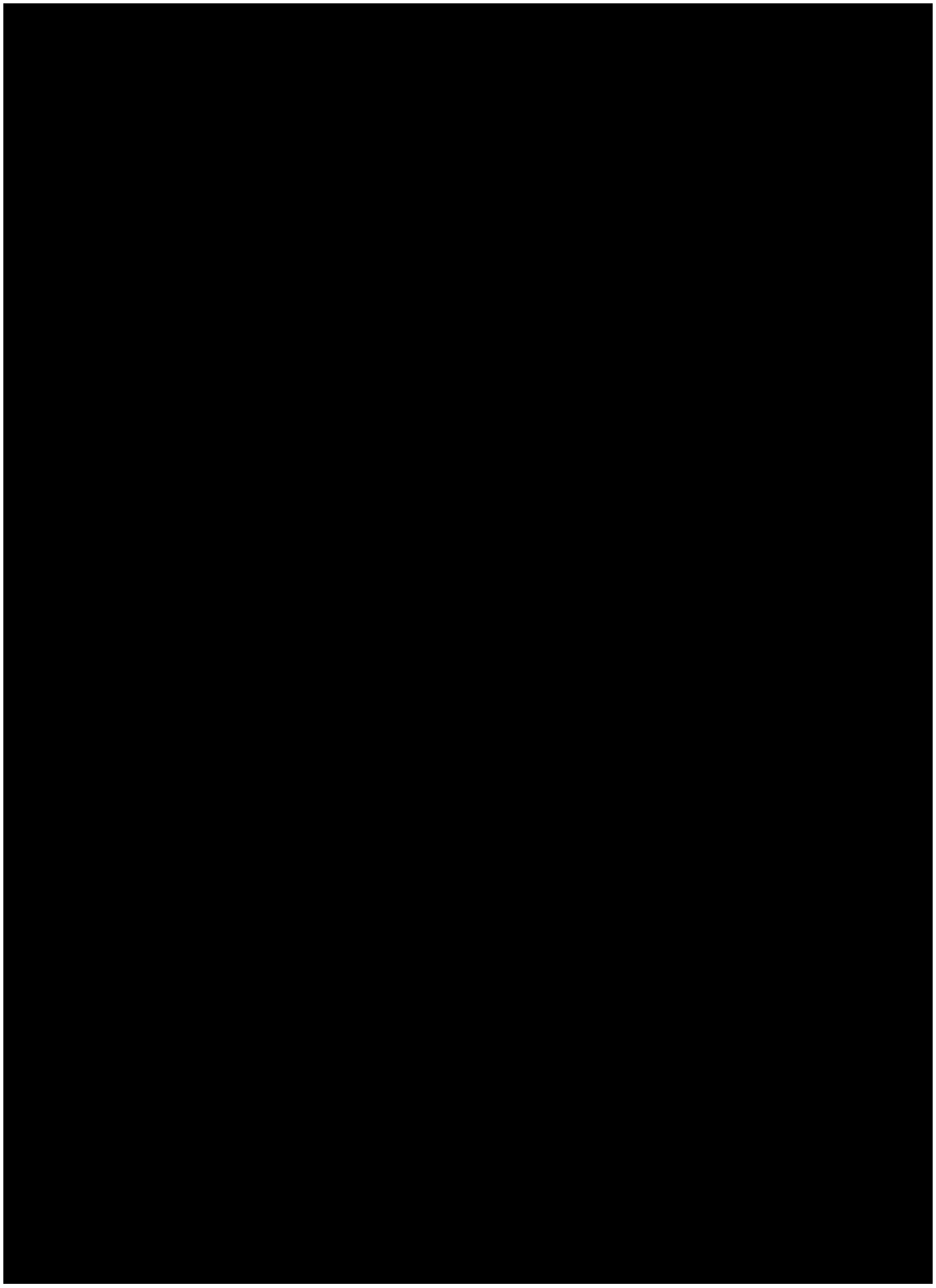


Figure 3.4-11 - HAC Transient Analysis Temperature Contours (1500 W)

Figure 3.4-13 - OSV Lid Temperature Contours (1500 W) at t = 3.4 hours.

3.5 Appendix

3.5.1 References

[3.1] Parker, "O-Ring Handbook," ORD 5700, 2007.

[3.2] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, Part D, *Materials*, 2010 Edition with 2011 Addenda.

[3.3] F. P. Incropera and D. P. DeWitt, in *Fundamentals of Heat and Mass Transfer*, Fifth ed., New York, John Wiley & Sons, Inc., 2002.

[3.4] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Code Cases: Nuclear Components, Case N-670-1, *Use of Ductile Cast Iron Conforming to ASTM A 874/A 874M-98 or JIS G5504-2005 for Transport and Storage Containments*, January 4, 2008.

[3.5] ASM International Handbook Committee, Metals Handbook, Volume 1, Properties and Selection: Irons, Steels, and High-Performance Alloys, Tenth ed., Materials Park, OH: ASM International, 1990.

[3.6] [redacted]

[3.7] F. P. Incropera, D. P. DeWitt, T. L. Bergman and A. S. Lavine, "Fundamentals of Heat and Mass Transfer," Seventh Edition, 2011.

[3.8] High Temperatures - High Pressures, "Thermal Conductivity of Nonporous Polyurethane," 2000.

[3.9] [redacted]

[3.10] Skolnik Industries, Inc., *Part No. ST1101N, Rev. A, 110 Gallon Open Head Drum,* Chicago, IL, 2012.

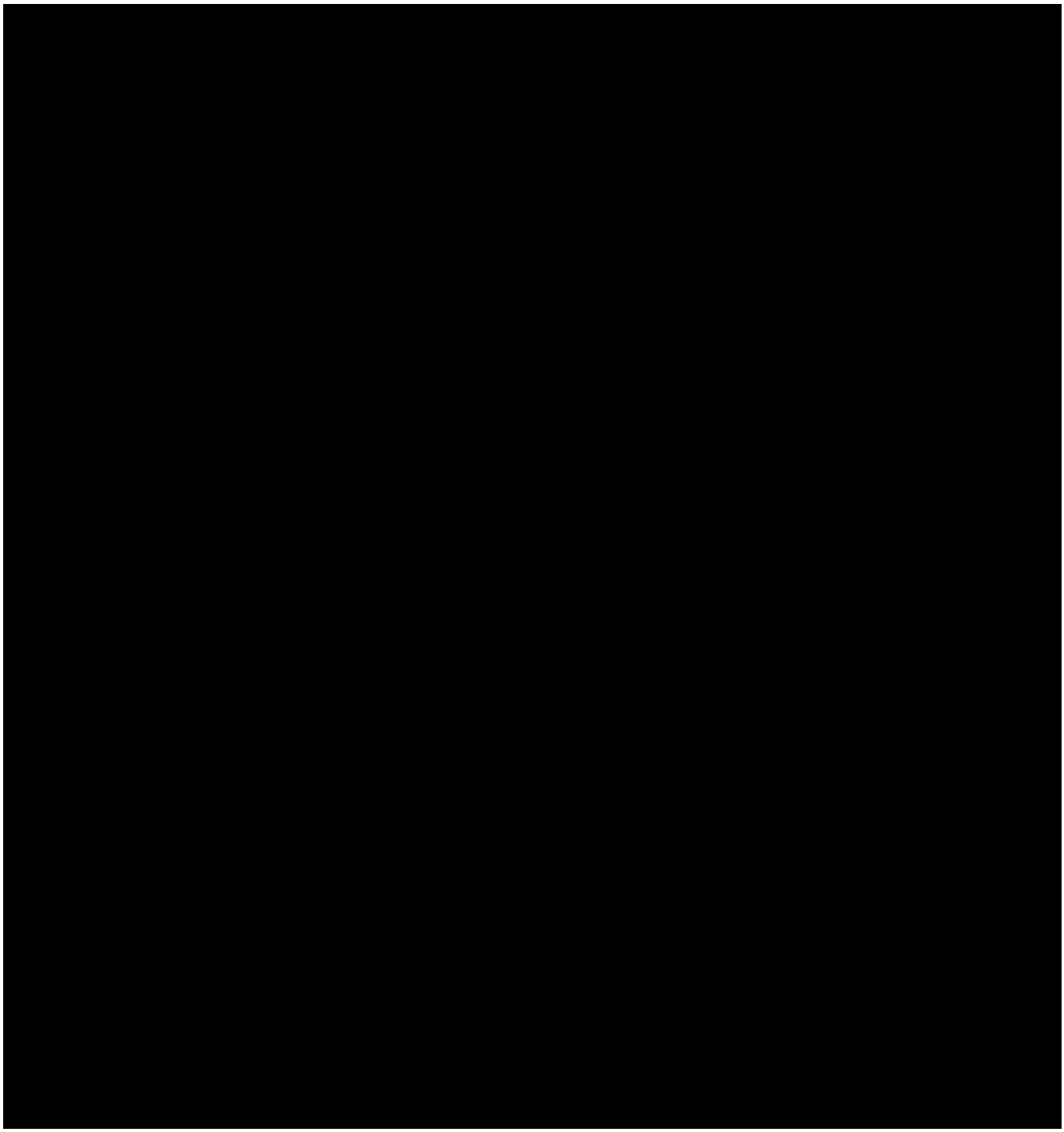
[3.11] Falcon Structures, "Conex Shipping Container Dimensions," [Online]. Available: https://www.falconstructures.com/falcon-box-plans. [Accessed 9 December 2017].

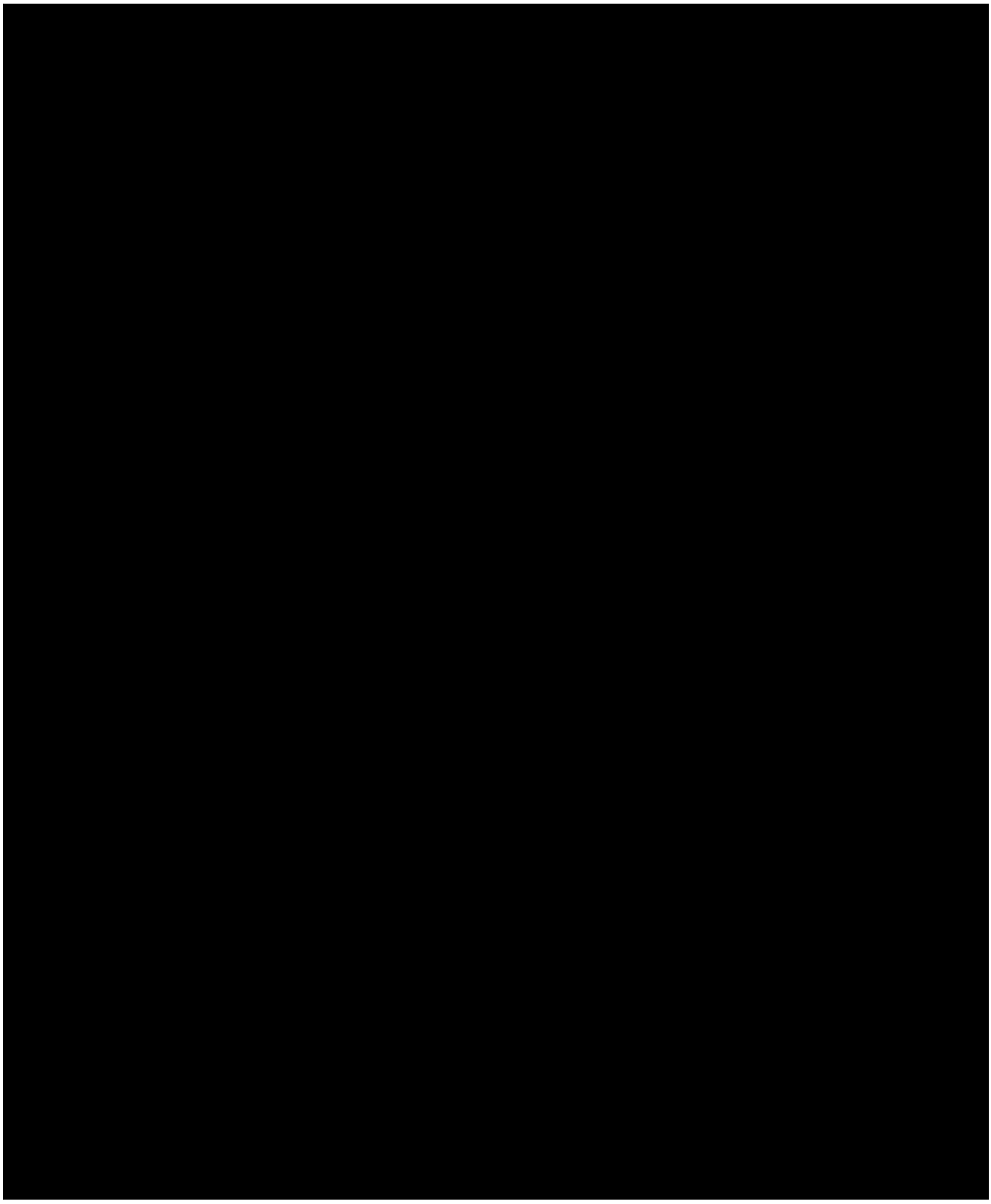
[3.12] J. H. Lienhard IV and J. H. Lienhard V, in *A Heat Transfer Textbook*, Fourth ed., Cambridge, Massachusetts: Phlogiston Press, 2012.

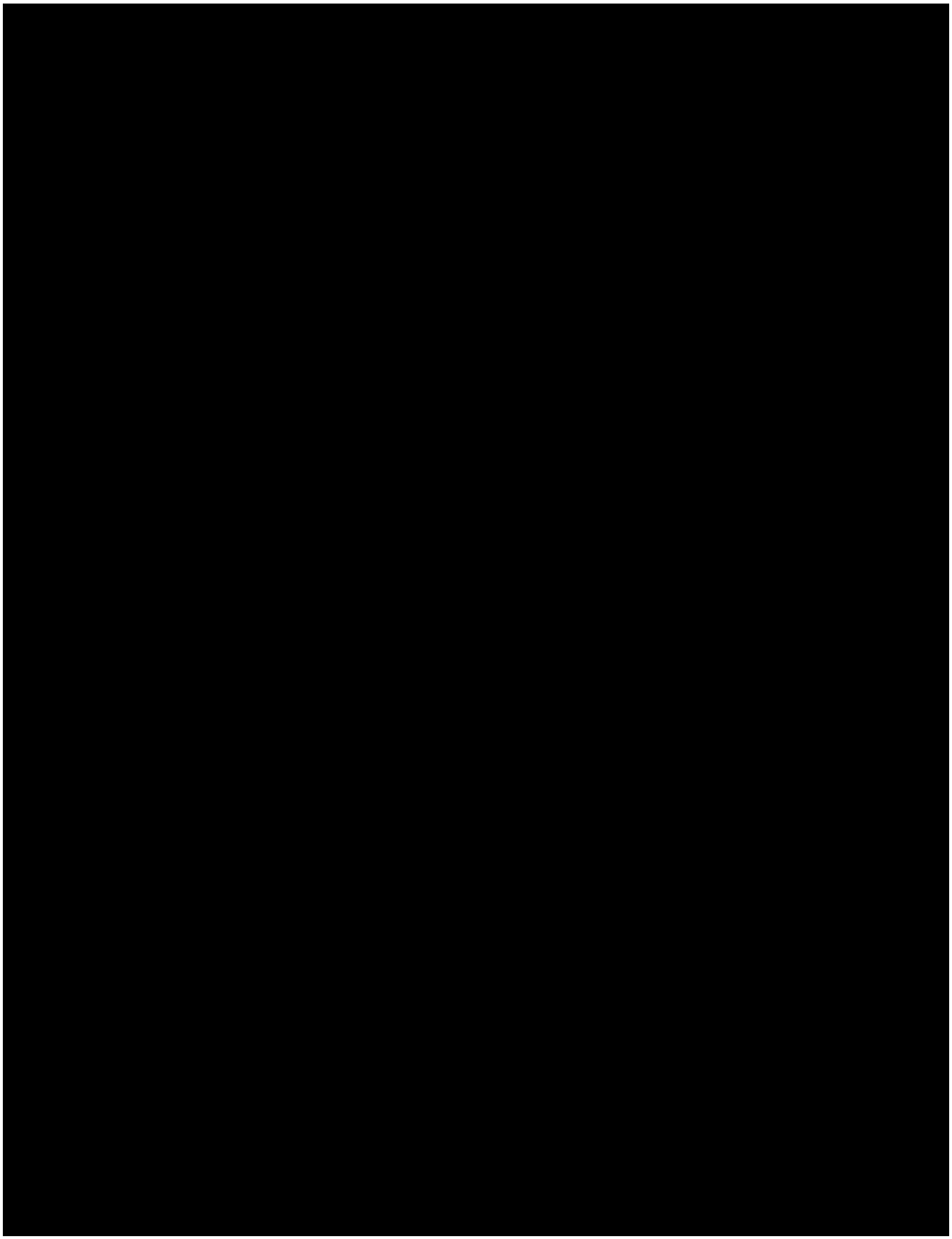
[3.13] E. C. Guyer, Ed., in Handbook of Applied Thermal Design, New York, McGraw-Hill, 1989.

3.5.2 Sensitivity Analyses of Modeling Parameters

The finite element models used to evaluate the package for general packaging standards, NCT, and HAC are described in Sections 3.3 and 3.4. The purpose of this section is to evaluate the sensitivity some modeling parameters have on the analyses.







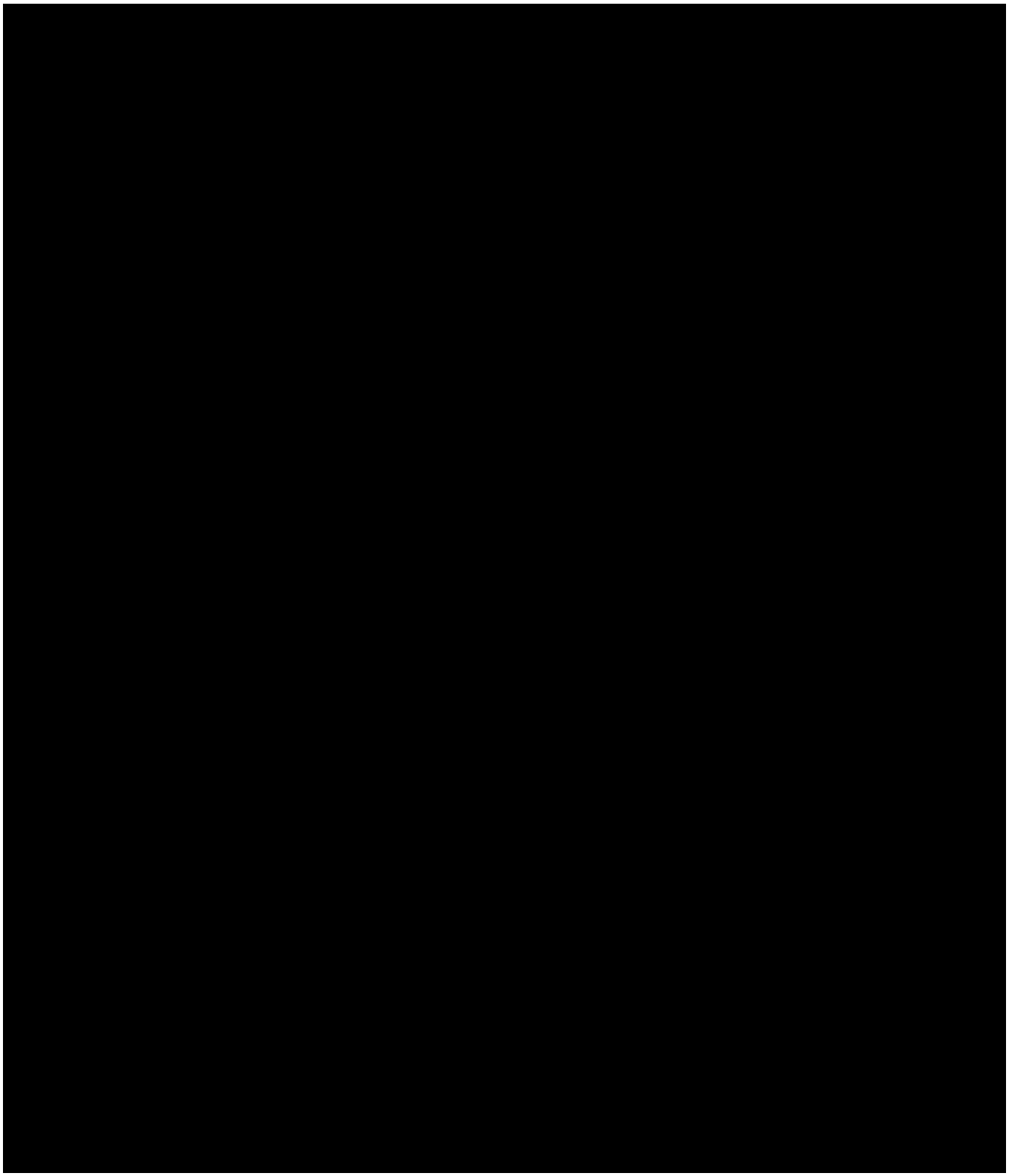


Table 3.5-1 - Maximum NCT Package Temperatures (110g vs 55g Drum)

[redacted]

Table 3.5-2 - Maximum HAC Package Temperatures for Two CCV Positions

[redacted]

Figure 3.5-1 - Comparison of the NCT Temperatures of the CCV Base Plate

Figure 3.5-2 - Comparison of the NCT Temperatures of the CCV Shell

Figure 3.5-3 - Comparison of the NCT Temperatures of the CCV Flange

Figure 3.5-4 - Comparison of the NCT Temperatures of the CCV Lid

Figure 3.5-5 - Comparison of the NCT Temperatures of the OSV Base

Figure 3.5-6 - Comparison of the NCT Temperatures of the OSV Lid

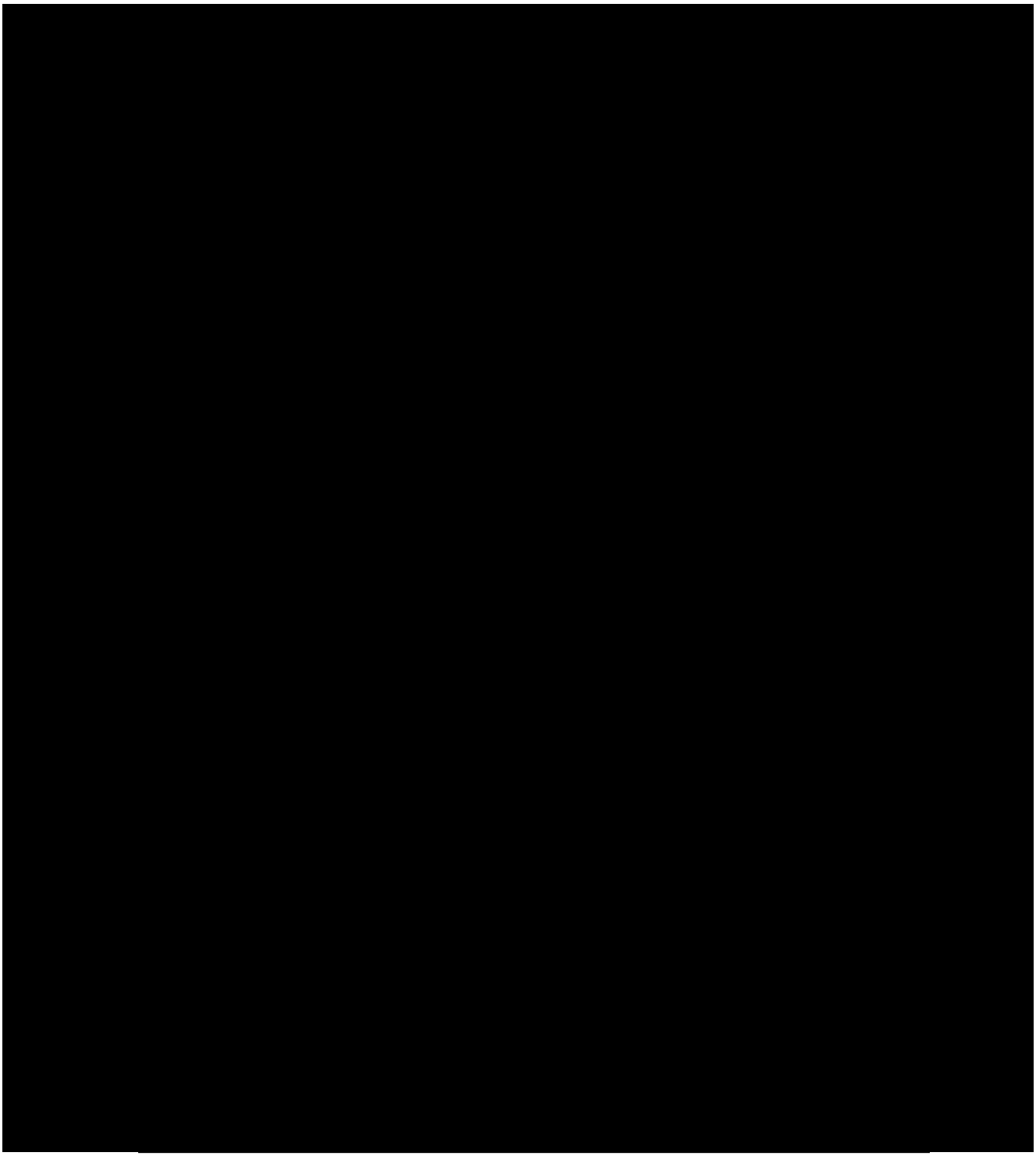


Figure 3.5-7 - HAC Temperature Contours When CCV O-ring Reaches is Maximum Temperature

Figure 3.5-8 - CCV O-ring Temperature Time-Histories for HAC (1500 W)

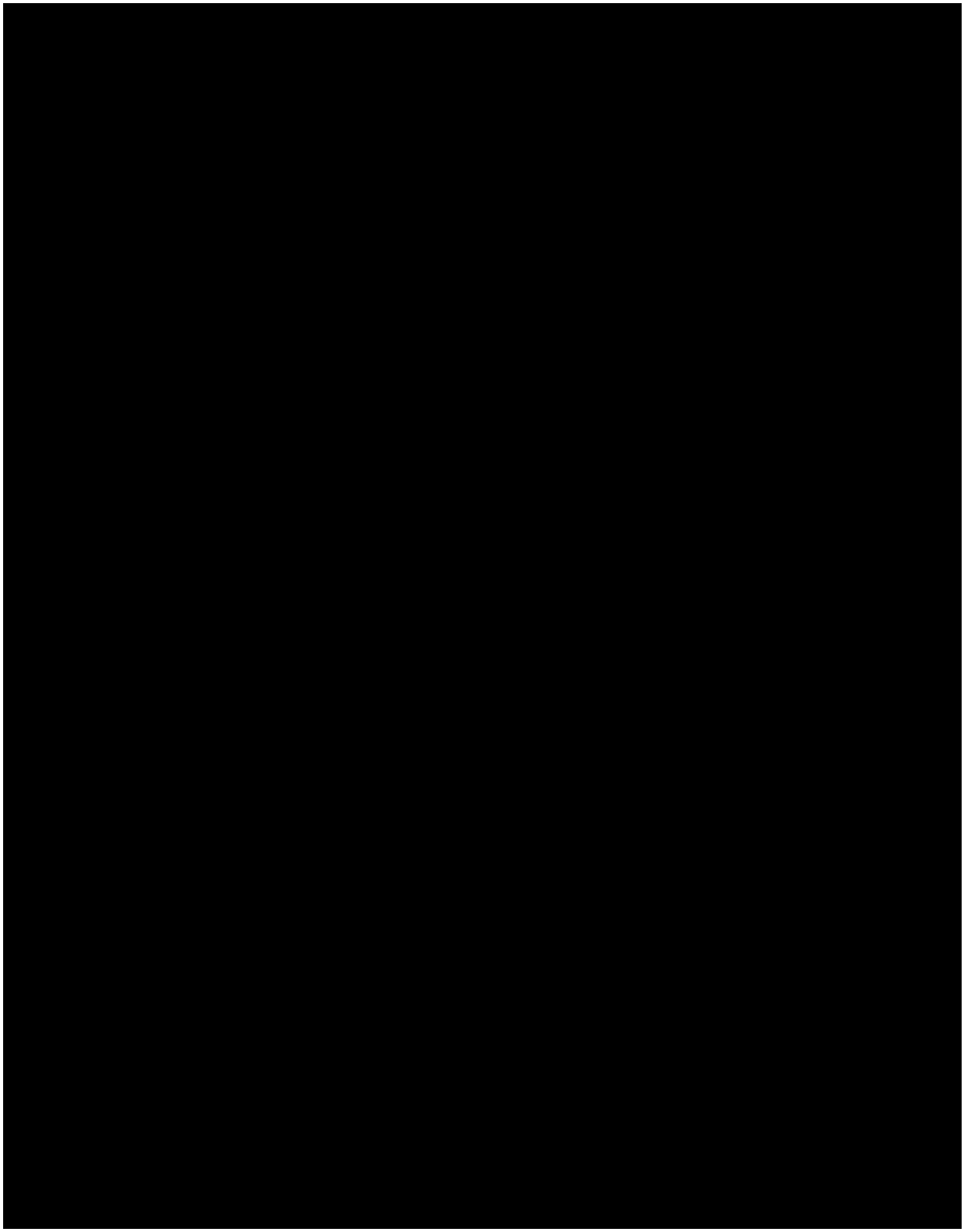


Figure 3.5-9 - CCV Maximum Seal Temperatures during HAC.

Figure 3.5-10 - Pre-Fire Steady-State Temperature Contours – 1500 W, [redacted] Side/Corner Foam

This page intentionally left blank.

Chapter 4
Containment

Table of Contents

4 CONTAINMENT 4-1

4.1 Description of the Containment System 4.1-1

4.2 Containment Under Normal Conditions of Transport 4.2-1
4.2.1 NCT Pressurization of the Containment Vessel 4.2-1
4.2.2 NCT Containment Criterion 4.2-1
4.2.3 Compliance with NCT Containment Criterion 4.2-1

4.3 Containment Under Hypothetical Accident Conditions 4.3-1
4.3.1 HAC Pressurization of the Containment Vessel 4.3-1
4.3.2 HAC Containment Criterion 4.3-1
4.3.3 Compliance with HAC Containment Criterion 4.3-1

4.4 Leakage Rate Tests for Type B Packages 4.4-1
4.4.1 Fabrication Leakage Rate Test 4.4-1
4.4.2 Maintenance Leakage Rate Test 4.4-1
4.4.3 Periodic Leakage Rate Test 4.4-1
4.4.4 Pre-shipment Leakage Rate Test 4.4-1

4.5 Appendix 4.5-1
4.5.1 References 4.5-1
4.5.2 Flammable Gas Calculations / Requirements 4.5-3
4.5.3 Chemical Compatibility of TRU Waste Contents 4.5-6
4.5.4 Hydrogen Concentration Calculations 4.5-7
4.5.5 Non-Compliant TRU Waste 4.5-27

List of Figures

Figure 4.1-1 Packaging Containment System 4.1-3
Figure 4.5-1 Hydrocarbon Propellant Combustion Pressures 4.5-54
Figure 4.5-2 Hydrocarbon Propellant Combustion Temperatures 4.5-54
Figure 4.5-3 Inert Gas Case Combustion Pressures 4.5-55
Figure 4.5-4 Inert Gas Case Combustion Temperatures 4.5-55
Figure 4.5-5 Radiolysis Gas Case Combustion Pressures 4.5-56
Figure 4.5-6 Radiolysis Gas Case Combustion Temperatures 4.5-56
Figure 4.5-7 Hydrogen Combustion Pressures 4.5-57
Figure 4.5-7 Hydrogen Combustion Temperatures 4.5-57
Figure 4.5-9 [redacted] Results Matrix 4.5-58
Figure 4.5-10 [redacted] Results Matrix 4.5-58

List of Tables

Table 4.5-1 LOC Values for Flammable Gases 4.5-34
Table 4.5-2 TRU Waste Contents - Flammability Limits 4.5-34
Table 4.5-3 TRU Waste Maximum Hydrogen G-Values and Activation Energies 4.5-34
Table 4.5-4 TRU Waste Minimum Hydrogen Release Rates 4.5-35
Table 4.5-5 Non-Compliant TRU Waste Maximum Pressures 4.5-36
Table 4.5-6 Properties of Liquefied Aerosol Propellants 4.5-37
Table 4.5-7 Aerosol Propellant and Hydrogen Characteristics 4.5-50
Table 4.5-8 Air/Helium Gas Mixtures 4.5-50
Table 4.5-9 Flammability Limits for Hydrogen Gas and Propellant Mixtures 4.5-50
Table 4.5-10 Radiolysis Gas Cases - Deflagration Parameters/Results 4.5-51
Table 4.5-11 Hydrogen Gas Cases - Deflagration Parameters/Results 4.5-51
Table 4.5-12 [redacted] Mixture Classification 4.5-52
Table 4.5-13 Energy Released from Hydrocarbon Fuel Burn 4.5-52
Table 4.5-14 CCV/Seal Combustion Temperature Change Calculation 4.5-53

4 CONTAINMENT

In accordance with the requirements of 10 CFR 71.43(f) and, the package is designed, constructed, and prepared for shipment to assure no loss or dispersal of radioactive contents as demonstrated to a sensitivity of 10^{-6} A_2 per hour in accordance with 10 CFR 71.51(a)(1), no significant increase in external surface radiation levels [i.e., more than 20% of the maximum radiation level at any surface of the package], and no substantial *reduction* on the effectiveness of the packaging under the NCT tests specified in 10 CFR 71.71. In addition, the package is designed, constructed, and prepared for shipment to assure no escape of Krypton-85 exceeding $10A_2$ in 1 week, no escape of radioactive material exceeding a total amount A_2 in 1 week, and no external radiation dose rate exceeding 10 mSv/h (1 rem/h) at 1 m (40 in) from the external surface of the package under the HAC tests specified in 10 CFR 71.73, in accordance with the requirements of 10 CFR 71.51(a).

This chapter describes the packaging's containment system design and how it meets the containment requirements under NCT and HAC tests and defines the criteria for leak rate testing during package fabrication, use, maintenance, and repair. The appendices in this chapter provide guidance for chemical compatibility and flammability requirements of the contents, and pressure calculations for the non-compliant content types (Content IDs 1-2A, 1-2B, and 1-2C).

This page intentionally left blank.

4.1 Description of the Containment System

The packaging has a simple, robust containment system design. Containment of radioactive material for the packaging is provided by the Cask Containment Vessel (CCV). The only welds within the containment boundary are the full-penetration welds connecting the CCV shell to the bottom plate and bolting flange. Other than the CCV lid closure and port cover closure, there are no penetrations to the containment system, and no valves or pressure relief devices of any kind. In accordance with the requirements of 10 CFR 71.51(c), the packaging does not rely on any filter or mechanical cooling system to meet containment requirements, nor does the containment system include any vents or valves that allow for continuous venting.

The CCV is comprised of a body weldment, bolted closure lid, bolted port cover, and the associated lid and port cover containment O-ring seals. A sketch of the CCV is included in Figure 4.1-1, with the pressure-retaining boundary. The top view is simplified to only show the components significant to the containment system, removing details such as test ports, lifting hoist ring locations, and alignment pins.

The CCV body is a solid austenitic stainless steel [redacted] weldment consisting of a [redacted] cylindrical shell, a [redacted] bottom plate, and a bolt flange. [redacted]

The CCV lid [redacted] austenitic stainless steel [redacted] plate with a stepped-edge design preventing any significant shear loading of the CCV closure bolts. [redacted]

The CCV port cover, which fits flush into the port opening of the CCV lid, is also a solid austenitic stainless steel [redacted] plate with [redacted]

[redacted] The inner O-rings form the leak-tight containment seal for the lid and the outer O-rings are used to facilitate leakage rate testing of the assembled closure.

The CCV is designed, fabricated, examined, tested, and inspected in accordance with the applicable requirements of Subsection NB of the ASME Code [4.1] with certain exceptions discussed in Chapter 2. The containment system materials of construction are evaluated in Section 2.2.1 and selected to avoid chemical, galvanic, or other reactions, discussed in Section 2.2.2. The materials of construction are compatible with each other and the chemical form of the payload.

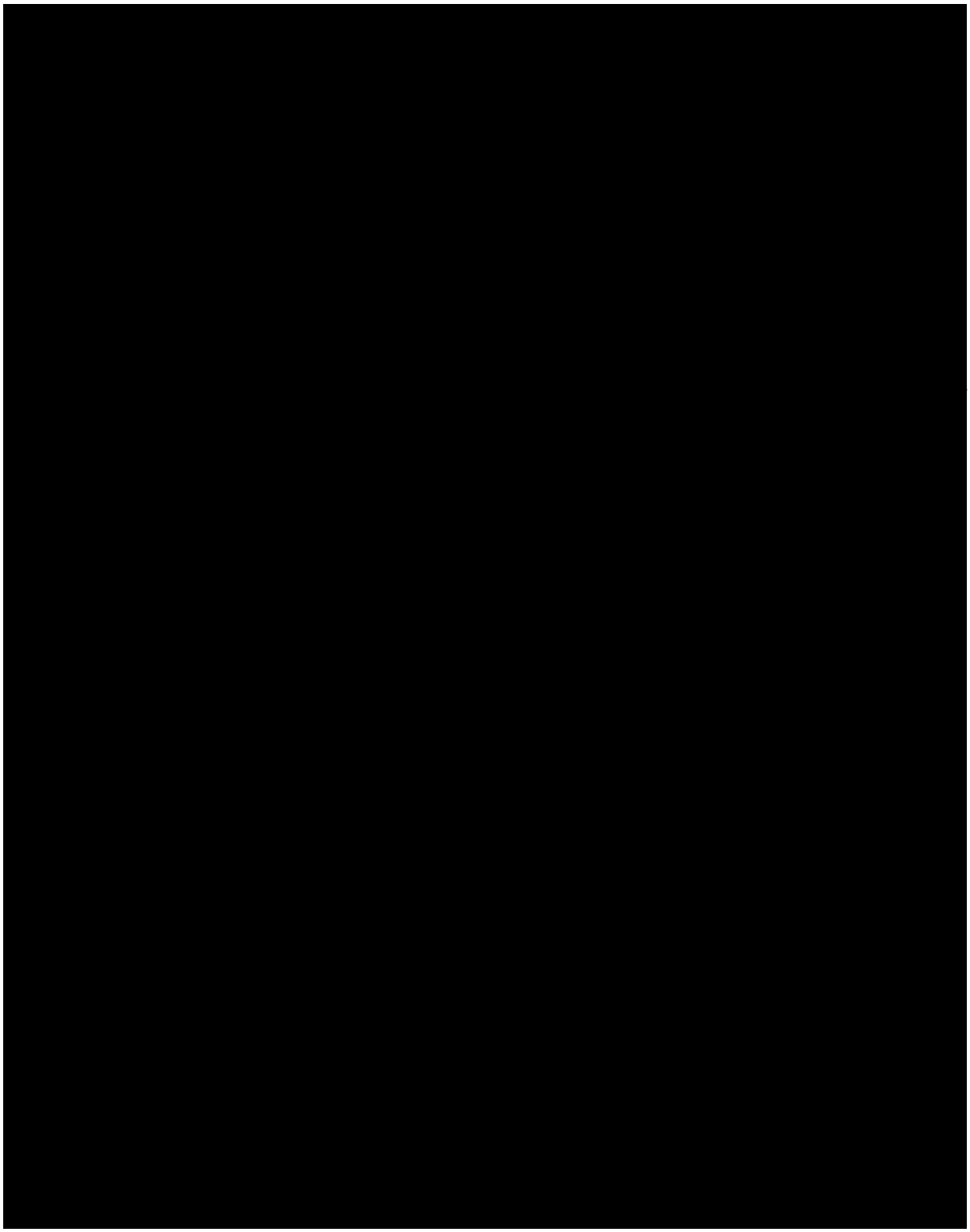


Figure 4.1-1 Packaging Containment System

This page intentionally left blank.

4.2 Containment Under Normal Conditions of Transport

4.2.1 NCT Pressurization of the Containment Vessel

The package maximum normal operating pressure (MNOP) is 100 psi (690 kPa) gauge, based on the definition of a Type B(U) packaging. Section 3.3.2 further discusses the NCT pressurization.

4.2.2 NCT Containment Criterion

The package is designed to a "leaktight" containment criterion per ANSI N14.5 [4.3]. Therefore, the containment criterion is 1×10^{-7} ref cm^3/sec.

4.2.3 Compliance with NCT Containment Criterion

Compliance with the NCT containment criterion is demonstrated by analysis. The structural evaluation in Section 2.6 shows there would be no loss or dispersal of radioactive contents, and that the containment boundary, seal region, and closure bolts do not undergo any inelastic deformation when subjected to the conditions of 10 CFR 71.71. The thermal evaluation in Section 3.3.1 shows the seals, bolts and containment system materials of construction do not exceed their temperature limits when subjected to the conditions of 10 CFR 71.71.

This page intentionally left blank.

4.3 Containment Under Hypothetical Accident Conditions

4.3.1 HAC Pressurization of the Containment Vessel

The containment evaluation for HAC is performed assuming the maximum package pressure is 225 psi (1551 kPa) gauge.

4.3.2 HAC Containment Criterion

The packaging is designed to a "leaktight" containment criterion per ANSI N14.5 [4.3]. Therefore, the containment criterion is 1×10^{-7} ref cm^3/sec.

4.3.3 Compliance with HAC Containment Criterion

Compliance with the HAC containment criterion is demonstrated by analysis. The structural evaluation in Section 2.7 shows there would be no loss or dispersal of radioactive contents, and that the containment boundary, seal region, and closure bolts do not undergo any inelastic deformation when subjected to the conditions of 10 CFR 71.73. The thermal evaluation in Section 3.4.3 shows the seals, bolts and containment system materials of construction do not exceed their temperature limits when subjected to the conditions 10 CFR 71.73.

This page intentionally left blank.

4.4 Leakage Rate Tests for Type B Packages

4.4.1 Fabrication Leakage Rate Test

The CCV assembly is tested during fabrication, prior to first use, to demonstrate the leakage rate of the containment system, as fabricated, does not exceed 1×10^{-7} ref cm^3/sec. The maximum allowable sensitivity for the fabrication leakage rate test is half of the required 1×10^{-7} ref cm^3/sec test criterion (i.e. 5×10^{-8} ref-cm^3/sec). The fabrication leakage rate test requirements are further described in Section 8.1.4.

4.4.2 Maintenance Leakage Rate Test

The CCV assembly is tested after maintenance of the CCV assembly to confirm the leakage rate of the containment system after maintenance, repair, or replacement of components does not exceed 1×10^{-7} ref cm^3/sec. The maximum allowable sensitivity for the maintenance leakage rate test is half of the required 1×10^{-7} ref cm^3/sec test criterion (i.e. 5×10^{-8} ref-cm^3/sec). The maintenance leakage rate testing and the replacement or repair activities requiring a maintenance leak rate test are further described in Section 8.2.2.2.

4.4.3 Periodic Leakage Rate Test

The CCV assembly is tested within 12 months prior to each shipment to confirm the leakage rate of the containment system does not exceed 1×10^{-7} ref cm^3/sec. The maximum allowable sensitivity for the maintenance leakage rate test is half of the required 1×10^{-7} ref cm^3/sec test criterion (i.e. 5×10^{-8} ref-cm^3/sec). The periodic leakage rate test requirements are further described in Section 8.2.2.2.

4.4.4 Pre-shipment Leakage Rate Test

Each packaging is tested prior to shipment to confirm the containment system is properly assembled for shipment. The pre-shipment leakage rate test is performed using the gas pressure rise method in ANSI N14.5, Section A.5.2, following the steps outlined in Section 7.1.3. The acceptance criterion for the pre-shipment leak test is no detected leakage when tested to a sensitivity of at least 1×10^{-3} ref-cm^3/sec. The pre-shipment leakage rate test requirements are further described in Section 8.2.2.3.

This page intentionally left blank.

4.5 Appendix

4.5.1 References

[4.1] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, *Class 1 Components*, 2010 Edition with 2011 Addenda.

[4.2] Parker Hannifin Corporation, *Parker O-Ring Handbook*, ORD 5700/USA, 2007.

[4.3] ANSI N14.5-2014, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*, American National Standards Institute, Inc., June 19, 2014.

[4.4] U.S. Nuclear Regulatory Commission (NRC), *"Standard Review Plan for Transportation Packages for Radioactive Material,"* NUREG-1609, March 1999.

[4.5] U.S. Nuclear Regulatory Commission (NRC), "*Clarifications of Conditions for Waste Shipments Subject to Hydrogen Gas Generation,*" IN84-72, 1984.

[4.6] National Fire Protection Association (NFPA), "*Standard on Explosion Prevention Systems,*" NFPA-69, 2014.

[4.7] U.S. Environmental Protection Agency (EPA), "*A Method for Determining the Compatibility of Hazardous Waste,*" EPA-600/2-80-076, 1980.

[4.8] U.S. Department of Energy (DOE), "*Transuranic Waste Acceptance Criteria for The Waste Isolation Pilot Plant,*" DOE/WIPP-02-3122, Rev.8, 2016.

[4.9] Lawrence Livermore National Laboratory, "*Hydrogen Generation in TRU Waste Transportation Packages,*" NUREG/CR-6673, May 2000.

[4.10] U.S. Department of Energy (DOE), "*RH-TRU Payload Appendices,*" Revision 3, 2014.

[4.11] [redacted]

[4.12] M. A. Johnsen, The Aerosol Handbook, Mendham, NJ: Wayne Dorland Company, 1982.

[4.13] [redacted]

[4.14] [redacted]

[4.15] M. A. Johnsen, The Aerosol Handbook, Mendham, NJ: Wayne Dorland Company, 1982.

[4.16] Lawrence Livermore National Laboratory, "Hydrogen Generation in TRU Waste Transportation Packages," NUREG/CR-6673, May 2000.

[4.17] [redacted]

[4.18] [redacted]

[4.19] Society of Fire Protection Engineers, SFPE Handbook of Fire Protection Engineering (Third Edition), Quincy, MA: National Fire Protection Association, 2002.

[4.20] [redacted]

[4.21] National Aeronautics and Space Administration (NASA), "Mechanical Design Handbook for Elastomers," NASA Contractor Report 3423, 1981.

[4.22] [redacted]

[4.23] [redacted]

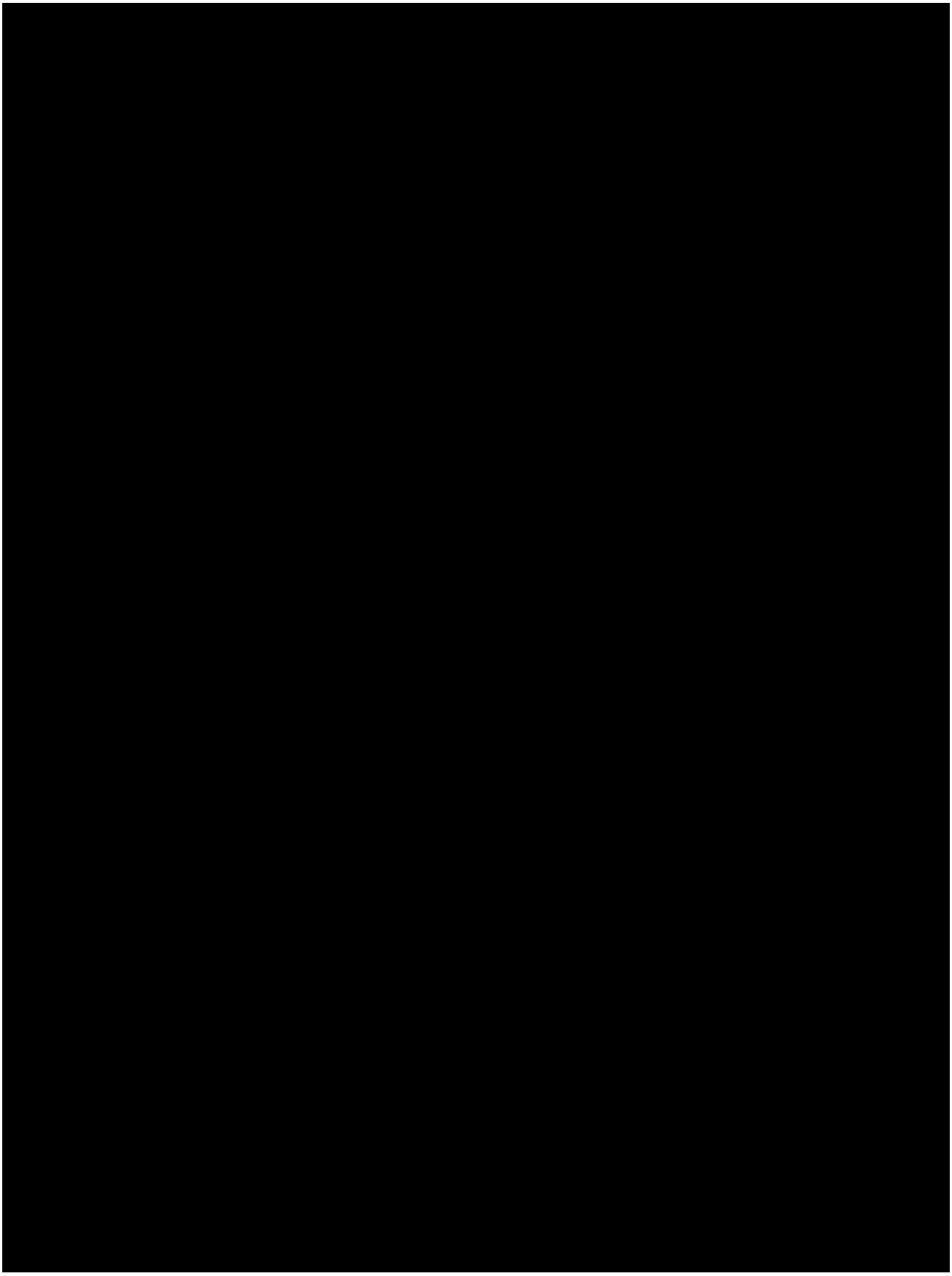
4.5.2 Flammable Gas Calculations / Requirements

Intermediate level waste contents (Content 1-1) present a potential risk for introduction of flammable gases from hydrogen gas through radiolysis (all TRU waste contents). Irradiated fuel waste contents (Contents 2-1 and 2-2) are inerted and dried, thus there is no flammability concern with this content type. For all TRU waste contents, limits are set to ensure there is no risk of a flammable gas mixture in any confinement region in the TRU waste contents due to radiolysis or the release of aerosol propellant gases.

Hydrogen gas generation from mechanisms other than radiolysis are insignificant. Hydrogen gas from chemical reactions is prohibited (see discussion in Section 4.5.3). As shown in Table 3.3-8, the maximum bulk-average temperature of the TRU waste contents in the CCV during normal transport is well below the 302°F (150°C) threshold temperature at which gas would be generated through thermal decomposition of plastics and other polymer waste materials in air. Given the estimated transportation time, nature of the waste, and environment of the payload, biological mechanisms are considered insignificant. The following subsections outline the limits for each content type to preclude the generation of a flammable gas mixture in the CCV.

4.5.2.2 Content Limits

Based on the differences between the TRU waste content types, different limits are set to restrict the components of the potential gaseous mixture in any confinement region of the TRU waste container.



[redacted]

4.5.3 Chemical Compatibility of TRU Waste Contents

Each TRU waste stream is defined by a content code, with a chemical list for the contents, based on process knowledge. Any chemical not included in the chemical list for the specific content code is limited to less than 1 wt.%, and the total quantity of trace materials is restricted to less than 5 wt.%. The chemical compatibility for a respective content code shall be addressed per the requirements outlined in EPA-600/2-80-076 [4.7] and Appendix H.3 of the WIPP Waste Acceptance Criteria [4.8]. All materials from the specified content code shall be chemically compatible (unless only present in trace amounts) to preclude chemical reactions resulting in:

1. Heat Generation
2. Fire
3. Explosion
4. Formation of toxic fumes
5. Formation of flammable gases
6. Volatilization of toxic or flammable substances
7. Formation of substances of greater toxicity
8. Formation of shock and friction sensitive compounds
9. Pressurization in closed vessels
10. Solubilization of toxic substances
11. Dispersal of toxic dusts mists and particles
12. Violent polymerization

4.5.4 Hydrogen Concentration Calculations

As stated in Section 4.5.2, regardless of whether the flammability control limit is based on fuel or oxidant restrictions, all limits are equated to a limiting hydrogen gas concentration based on the radiolysis of water (see Table 4.5-2). Thus, for all TRU waste contents it is necessary to calculate the concentrations of hydrogen gas in the confinement layers of the TRU waste containers over time, to demonstrate compliance with the imposed limits. The hydrogen gas calculations are not restricted to the radiolysis of water only, but all hydrogenous materials that could generate hydrogen gas through radiolysis must be considered. As contents under Contents 2-1 and 2-2 do not include hydrogenous materials of flammable gases, this content type is exempt from these hydrogen gas calculations.

The requirements for hydrogen gas generation calculations to meet the hydrogen concentration limit are outlined in the following subsections. Compliance with the hydrogen gas limits must be demonstrated for each shipment of the package with TRU waste contents. Note that Volatile Organic Compounds (VOCs) are limited to a concentration of 500 ppm in the headspace of the container. With VOCs restricted to below this limit, they do not affect the flammability of the gaseous mixture in the contents. The following methods for hydrogen concentration calculations are based on the guidance provided in NUREG/CR-6673 [4.9].

4.5.4.1 G-value Data

The G-values used for flammable gas generation calculations are specific to the contents in a given payload, based on the chemical properties of the materials. The bounding G-values shall be used for the calculations of a given content based on the materials present, and must be selected from acceptable industry standard references, such as Appendix D of NUREG/CR-6673 [4.9]. The following factors are neglected from consideration for G-values based on the information in Section 2.4 of NUREG/CR-6673 [4.9]:

1. *The Linear Energy Transfer (LET) Effect*. The difference between radiations from LET are small and reference values are based on bounding conditions.

2. *Pressure*. G-values decrease with increasing pressure. The internal pressure of the CCV will always be greater than 1 atm, basing the G-values on experiments at 1 atm or in vacuum is bounding.

3. *Atmosphere*. G-values are maximized at vacuum conditions, thus as long as the reference G-values are from experiments in vacuum they are bounding.

4. *Total Absorbed Dose (matrix-depletion effect)*. G-values decrease with increasing total dose. Neglecting this effect maximizes the calculated flammable gas generation rate. However,

this effect may be considered as outlined in Section 2.2 of the DOE document RH-TRU Payload Appendices [4.10]. Per this document, the dose dependent G-values are applicable after 0.012 watt-years.

5. *Dose Rate*. The elevated dose rate and thermal effects are mitigated by removing oxygen from the system before the irradiated materials are heated. The CCV is always evacuated and backfilled with helium prior to transport, removing nearly all oxygen from the system.

6. *Material Composition*. Maximum G-values are measured for commercial materials to provide more realistic upper bounds for radiolytic gas generation than for pure polymers.

Radiation Based G-values

The G-value for a given material, can vary depending on the fraction of the alpha, beta, and gamma energy, when dose dependent G-values are used. If the bounding G-values are used, there is no calculation required for the G-value based on the radiation emitted in the waste. This case maximizes the hydrogen generation, and consequently the hydrogen concentration, in the innermost confinement layer. With this assumption, no adjustment of the G-values is necessary for the fractions of α, β, and γ radiation emitted from the contents, and the referenced bounding G-values can be used for the hydrogen gas calculations. For this case, the effective G-value of the contents is calculated as the maximum value of the materials present in the TRU waste:

$$G_{eff} = \max(G_i, \ldots, G_M)$$

Where,

G_{eff} = Effective G-value of contents (molecules / 100 eV)

G_i = Maximum G-value of material i (molecules / 100 eV)

M = Total number of hydrogen generating materials in the contents

For the dose dependent G-values (applicable for any contents loaded for > 0.012 watt-years) the effective G-value can be calculated depending on the materials and portions of the radiation particles emitted (α, γ, or β), per the guidance of Section 3.3.1 in NUREG/CR-6673 and the information in Appendix 2.2 of the DOE document RH-TRU Payload Appendices [4.10]. This calculation assumes that all energy emerges from the radioactive particles and is absorbed into the material M. The G-value for each particle type ($G_{M,p}$) is selected based on the material with the greatest G-value for the respective particle. For example, for contents with polyethylene and cellulose, the $G_{M,\alpha}$ and $G_{M,\beta}$ are based on cellulose, but $G_{M,\gamma}$ are based on polyethylene (see values listed in Table 4.5-3).

$$G_{eff} = \sum \lambda_p \cdot G_{M,p}$$

Where,

G_{eff} = Effective G-value of contents (molecules / 100 eV)

λ_p = Fraction of decay energy from particle type p

$G_{M,p}$ = G-value of material M based on incident particle type p (molecules / 100 eV)

M = Material with the largest hydrogen gas G-value for particle type p.

p = Particle type (α, β, or γ)

Temperature Adjustment

The sources for G-values typically provide the data at 70°F. Thus, these values must be adjusted to account for the temperature effect on radiolytic gas generation. This temperature effect is accounted for using the following equation (based on EQN 2.2 in NUREG/CR-6673) [4.9]. It can be noted the higher the temperature is the greater the increase in the G-value will be. Thus, the adjustment is based on the maximum gas temperature in the CCV calculated for NCT. Note that dose dependent G-values for α and β particles are not temperature dependent, and thus do not need to be adjusted for temperature.

$$G_{T2} = G_{T1} \cdot \exp\left(\left(\frac{E_a}{R}\right)\left(\frac{T_2 - T_1}{T_2 T_1}\right)\right)$$

Where,

G_{T2} = G-value at Temperature T_2 (molecules/100 eV)

G_{T1} = G-value at Temperature T_1 (molecules/100 eV)

E_a = activation energy for gas generating material (kcal/mol)

R = 1.9858775E-3 kcal/mol-K, Gas law constant

T_2 = Maximum volumetric average temperature of CCV cavity gas for NCT from Table 3.3-8 in K.

T_1 = 294.26 K (or temperature from G-value source data)

Some of the typical G-values of hydrogenous materials present in TRU waste streams are provided in the DOE document RH-TRU Payload Appendices [4.10]. The G-values and

activation energies of the materials in Table 4.5-3 are based on the information in Tables 2.2-1 and 2.2-2 of Reference [4.10]. For other solid organic materials not listed in this table it is acceptable to use the value for polyethylene as a bounding value. Solidified organics are not acceptable as contents in the package.

Flammable gas generation rate

Using the effective G-value and decay heat of the contents, the flammable gas generation rate (FGGR) for the specific TRU waste contents can be calculated:

$$\mathrm{FGGR} = \frac{\mathrm{Q}}{100} \cdot \left(\frac{(\mathrm{G_{eff}})}{(\mathrm{N_A}) \cdot \left(1.602\mathrm{E}-19 \frac{\mathrm{W \cdot s}}{\mathrm{eV}}\right)} \right)$$

Where,

FGGR = Flammable gas generation rate (moles/s)

Q = Decay heat of radioactive contents (W)

N_A = Avogadro's number (6.023E23 molecules/mole)

The decay heat of the contents is determined based on the radionuclide inventory of the contents in the TRU waste container and a standard reference for isotopic decay heat values (e.g. the [redacted] module in the [redacted] code package [4.11]).

4.5.4.2 Release Rate Data

The release rates used for calculating the concentration of flammable gas are specific to the materials of the confinement layers in a given payload. The release rates used for the calculations of a given content are based on the confinement layers present in the TRU waste container. Note that any items that allow the free release of hydrogen (e.g. open or punctured bags) are not confinement layers. The sources for release rates typically provide the data at 25°C (77°F). Thus, these values must be adjusted to account for the temperature effect on release rates for each confinement barrier. The release rates vary with temperature to the 1.75 power ([4.10], Section 2.5.3), with lower temperatures further restricting the release of hydrogen, and increasing the hydrogen concentration. The temperature effect is accounted for using the following equation:

$$\mathrm{RR_{T2}} = \mathrm{RR_{T1}} \cdot \left(\frac{T_2}{T_1}\right)^{1.75}$$

Where,

RR_{T2} = Release rate at T_2 (mol/s/mol fraction)

RR_{T1} = Release rate at T_1 (mol/s/mol fraction)

T_2 = Temperature 2: Minimum Temperature for NCT 233 K (-40°C)

T_1 = Temperature 1: 298K (or temperature from Release Rate source data)

Based on the information provided in Table 2.5-1 of the RH-TRU Payload Appendices, the release rates provided in Table 4.5-4 are acceptable for use in hydrogen gas calculations for the package with TRU waste contents. Any confinement layer not listed in Table 4.5-4 shall be demonstrated to have a hydrogen release rate greater than or equal to one of the values specified in Table 4.5-4, through testing or analysis. For a heat-sealed bag, the hydrogen release rate can be calculated as follows:

$$RR = \frac{\rho A_P P_g}{x_p} \frac{\text{mole}}{22{,}400\ \text{cm}^3\ (\text{STP})}$$

Where,

RR = Release Rate of hydrogen (mole/sec/mol fraction H_2)

ρ = Hydrogen permeability (cm^3 (STP) cm^{-1} (cm Hg)$^{-1}$ s^{-1}), PVC=3.6E-10 / poly=8.6E-10

A_p = Permeable surface area (cm^2)

P_g = Gas Pressure (76 cm Hg)

x_p = Bag thickness (cm)

The release rates of all leaking confinement layers in a TRU waste container can be combined into an effective release rate, T_{eff}, or an effective resistance, R_{eff}. The resistance of a layer is calculated as the inverse of the release rate. The effective resistance or release rate can be calculated as follows:

$$T_{eff} = \frac{\prod_i^N RR_i}{\sum_i^N RR_i} \qquad R_{eff} = \sum_{i=1}^{N} \frac{1}{RR_i}$$

Where,

T_{eff} = Effective release rate of all confinement layers (mole/sec/mol fraction H_2)

R_{eff} = Effective resistance to the release of hydrogen

RR_i = Release Rate of confinement layer i

N = Total number of confinement layers in the contents

4.5.4.3 Hydrogen Gas Accumulation Calculations

For the calculation of the hydrogen gas concentration in the TRU waste contents, the package may use the method outlined in Section 4.2 of NUREG/CR-6673 [4.9], or the simplified approach outlined in this section.

NUREG/CR-6673 Calculation

Section 4.2 in the NUREG outlines the hydrogen mole balance equations for multiple configurations of waste containers (i.e., nested leaking enclosures in a non-leaking enclosure). More specifically, sections 4.2.2.1 and 4.2.2.5 of NUREG/CR-6673 [4.9] provide the approaches for calculating the hydrogen concentration in nested leaking enclosures, with a non-leaking outer enclosure at a given time, t. With the equations outlined in these sections, and the Content specific hydrogen limits listed in Table 4.5-2, the time to reach the hydrogen concentration limit can be calculated based on the TRU waste container confinement volumes and release rates. Section 4.2.2.5 in the NUREG provides a generalized approach for a single content that combines all leaking confinement regions into a single effective leaking confinement layer. For this calculation n_1 and n_2 are the number of moles of gas in the innermost confinement region and in the region between the CCV and TRU waste container, respectively. All volumes between confinement regions are considered to be zero. The void volume in the innermost confinement region is based on the geometry and free space of the region. If this volume is unknown or cannot be determined, it can be set to a bounding value of one (1) L, as discussed in Section 2.5.3 of the RH-TRU Payload Appendices. The void volume in the CCV is calculated based on the total void in the empty CCV (638.9 L), minus the total TRU waste container volume (e.g. 55-gallon drum volume), minus the shoring volume (assumed at 56 L). Both volumes are used to calculate the number of moles of gas using the ideal gas law, based on initial loading conditions (P=1 atm and T=294.26 K). Per EQN 4.35 in Section 4.2.2.5 of the NUREG [4.9]:

$$X_i(t) = \frac{A \cdot S}{(A+B)^2} - \frac{A \cdot S \cdot e^{-t \cdot (A+B)}}{(A+B)^2} + \frac{B \cdot S \cdot t}{(A+B)}$$

Where,

$X_i(t)$ = Hydrogen volume fraction in the innermost confinement region at time t.

$S = FGGR/n_1$

$A = T_{eff}/n_1$

$B = T_{eff}/n_2$

The initial conditions for this calculation is $X_i(0) = 0$, which is considered appropriate, as the evacuation process removes nearly all gas from the system, and the 1 vol% oxygen initial condition is considered in the set limits (See Section 4.5.1.2).

With the equation above, the time at which the volume fraction of hydrogen in the innermost confinement region reaches the limit for the respective content can be determined. Per the requirement of IN84-72 [4.5], the calculated shipment time, t, must be cut in half to set the allowable shipment time for the specific TRU waste content analyzed.

Simplified Calculation Method

This simplified calculation can be used in lieu of the NUREG/CR-6673 [4.9] calculation for an unquantified innermost confinement region volume. For the initial conditions of the simplified approach, it is assumed that the concentration and flow of hydrogen through the confinement layers of the TRU waste contents has reached steady state, prior to CCV closure. At steady state condition, the flow of hydrogen across all confinement layers is equal to the hydrogen generation rate. This assumption neglects the removal of nearly all hydrogen from the system during the evacuation process, prior to shipment.

Once the CCV is closed, with the TRU waste contents inside, the hydrogen concentrations in the confinement layers and the CCV increase, as it is now a closed system. The mole fraction of hydrogen accumulating in the CCV is calculated by assuming that all the hydrogen generated is released into the CCV cavity. The total moles of hydrogen that will accumulate in the CCV cavity at time, t, is:

$$N_{CCV} = (FGGR)(t)$$

Where,

N_{CCV} = Total moles of hydrogen accumulated in the CCV (moles)

FGGR = Flammable gas generation rate (moles/s)

t = Shipment time (s)

The total mole fraction in the CCV at time, t, is set as the ratio of the total moles of hydrogen generated to the initial number of moles in the CCV cavity upon closure. With hydrogen treated as an ideal gas, this equation can be reduced to:

$$X_{CCV} = \frac{N_{CCV}}{N_0} = \frac{N_{CCV}}{(P)(V_{Void})/RT} = \frac{(FGGR)(t)}{(P)(V_{Void})/RT}$$

Where,

X_{CCV} = Total hydrogen mole fraction in the CCV

N_0 = Total moles of gas in the CCV at time of closure (moles)

P = Pressure inside CCV, assumed to be isobaric at 1 atm

V_{Void} = Void volume in the CCV, i.e. $V_{CCV} - V_{Contents} - V_{Shoring}$ (Liters)

R = Gas constant (0.082057 atm·L/mol·K)

T = Absolute temperature of air at the time CCV closure, assumed to be 70°F (294.26 K)

The void volume in the CCV, V_{Void}, is calculated based on the total void in the empty CCV [redacted] minus the total TRU waste container volume (e.g. 55-gallon drum volume), minus the shoring volume [redacted]

The total hydrogen mole fraction in the innermost container can be calculated as follows:

$$X_i = X_{CCV} + (FGGR)(R_{eff})$$

Where,

X_i = Hydrogen mole fraction in the innermost container (content specific limit)

R_{eff} = Effective resistance to the release of hydrogen (sec/mole)

Rearranging this equation for X_{CCV}, and plugging it into the previous equation, results in the following (with values for P, R, and T combined):

$$X_i - (FGGR)(R_{eff}) = \frac{(FGGR)(t)}{(0.04141 \cdot V_{Void})}$$

The above equation can be solved for time, t, to determine the shipment time required to reach a hydrogen gas concentration at the limit for the respective content in the innermost confinement layer:

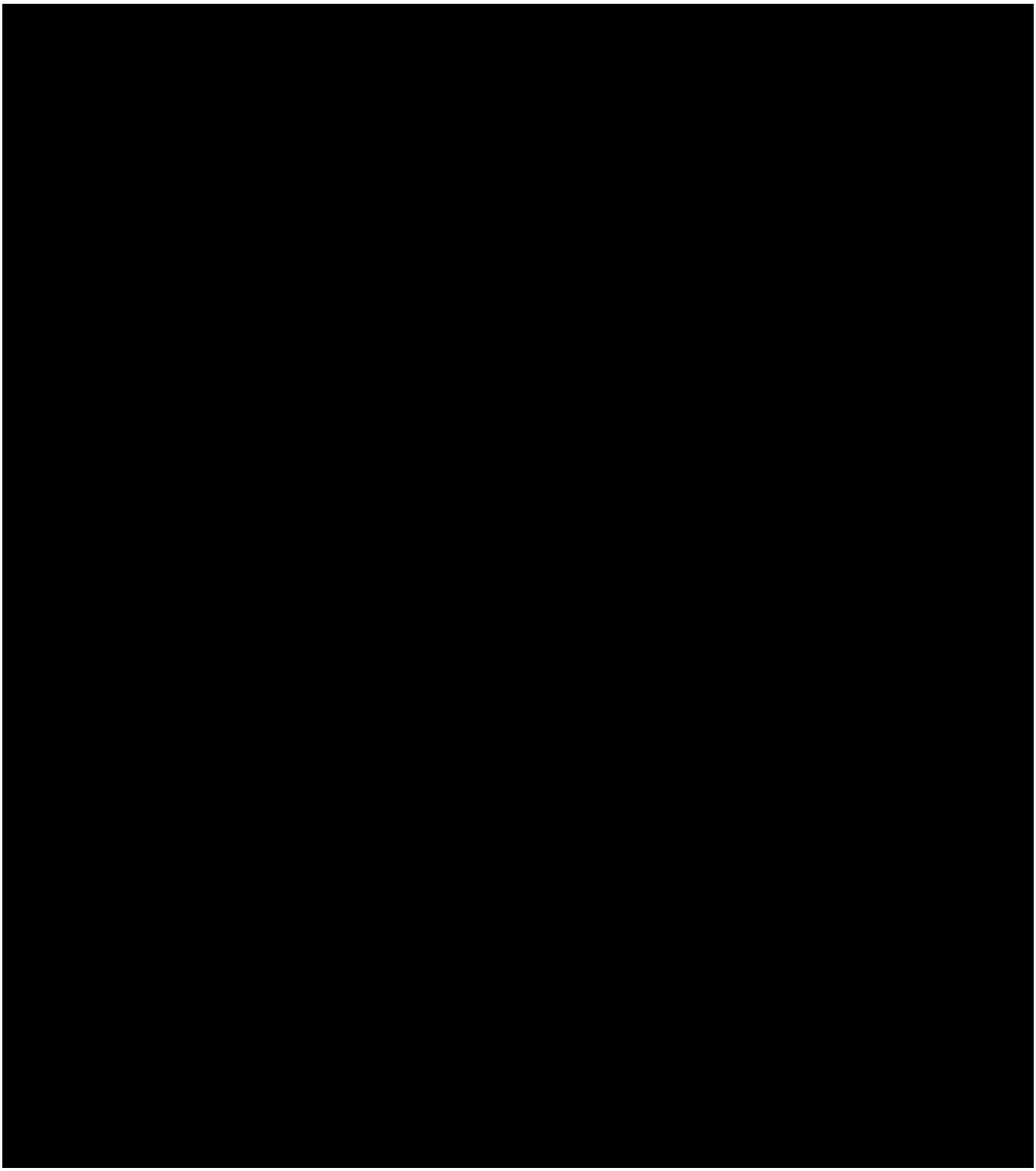
$$t = (0.04141 \cdot V_{Void}) \cdot \left(\frac{X_i}{(FGGR)} - (R_{eff}) \right)$$

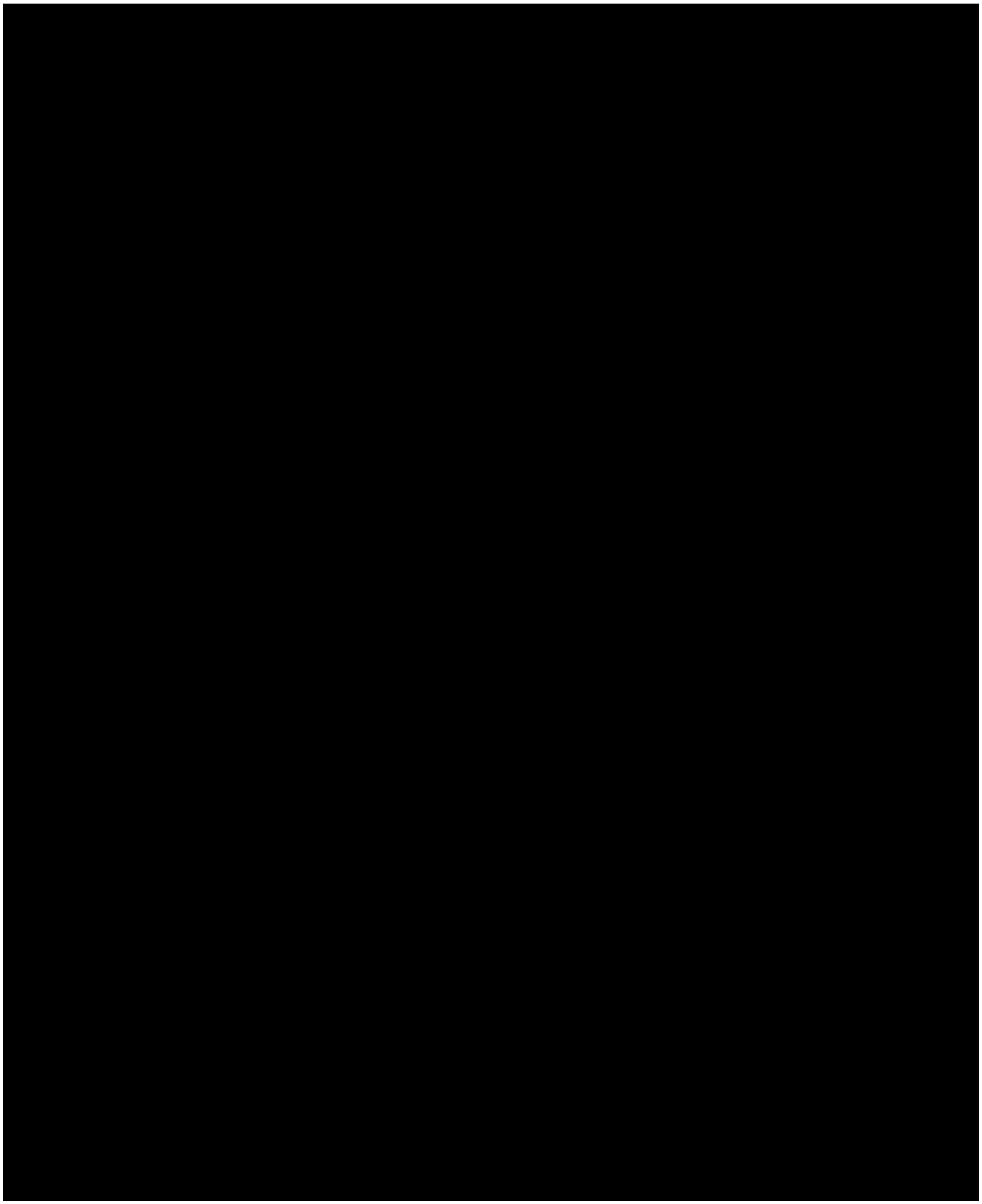
Per the requirement of IN84-72 [4.5], the calculated shipment time, t, must be cut in half to set the allowable shipment time for the specific TRU waste content analyzed.

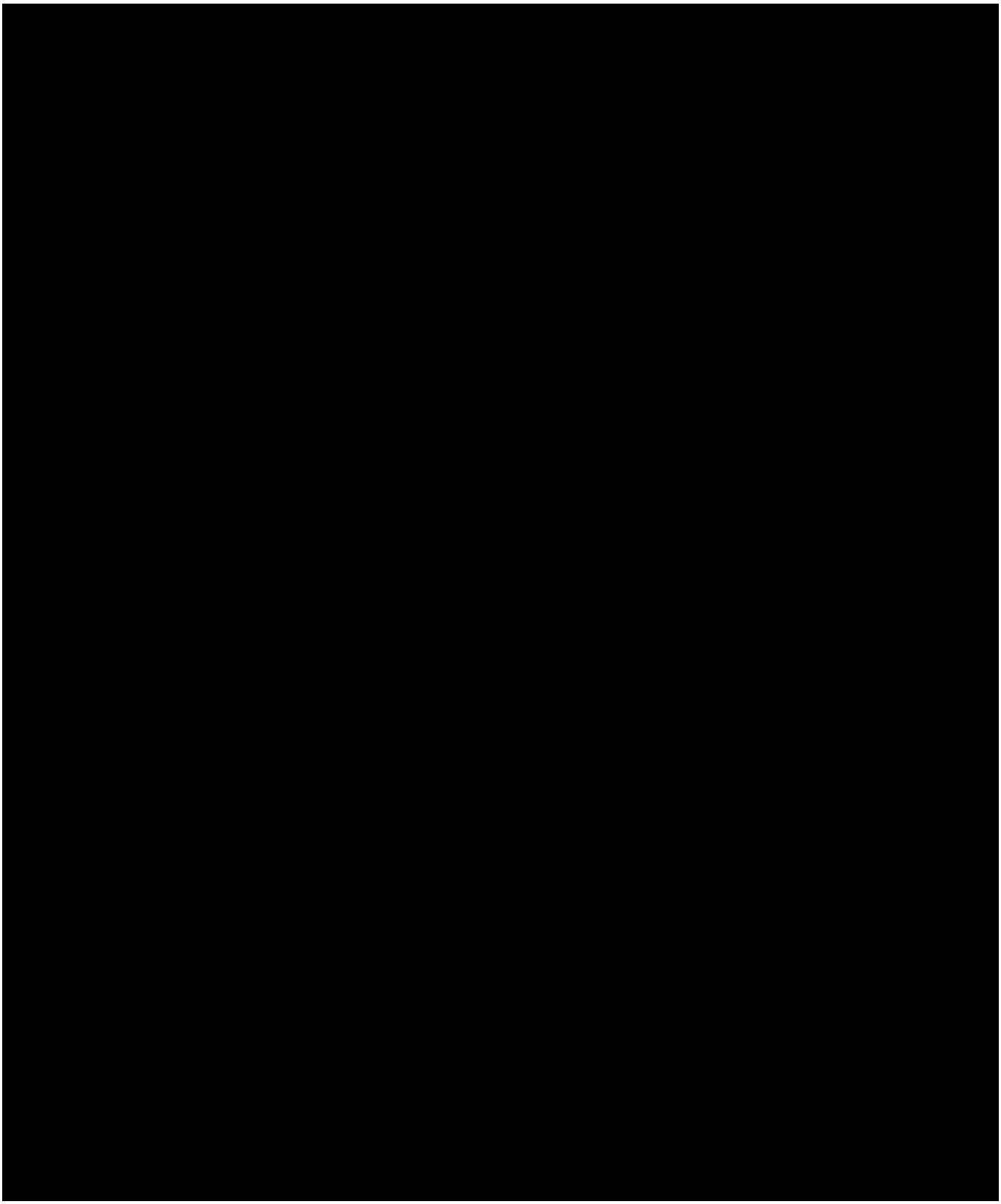
Also, for both the NUREG/CR-6673 [4.9] and simplified calculation method, as opposed to a single bounding calculation considering the G-value at the maximum temperature and the release rates at the minimum temperature, it is acceptable to perform two separate calculations. One calculation with both the G-value and release rates at the minimum temperature of -40°C (233K) and one with both the G-value and release rates at the maximum temperature of 229 °F (382.6 K). The transport time is then based on the limiting case between the hot and cold calculations.

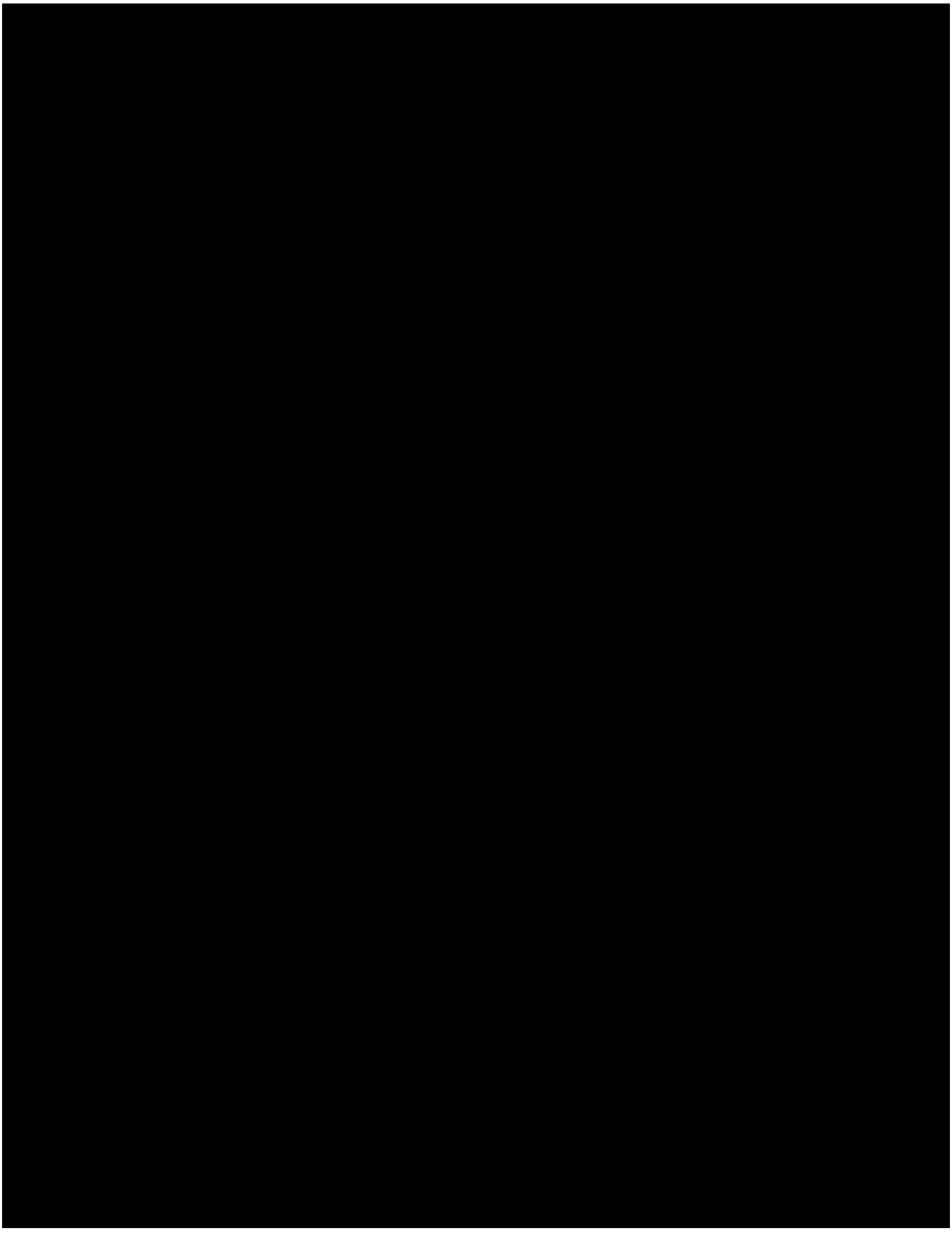
4.5.4.4 Example Hydrogen Gas Accumulation Calculations

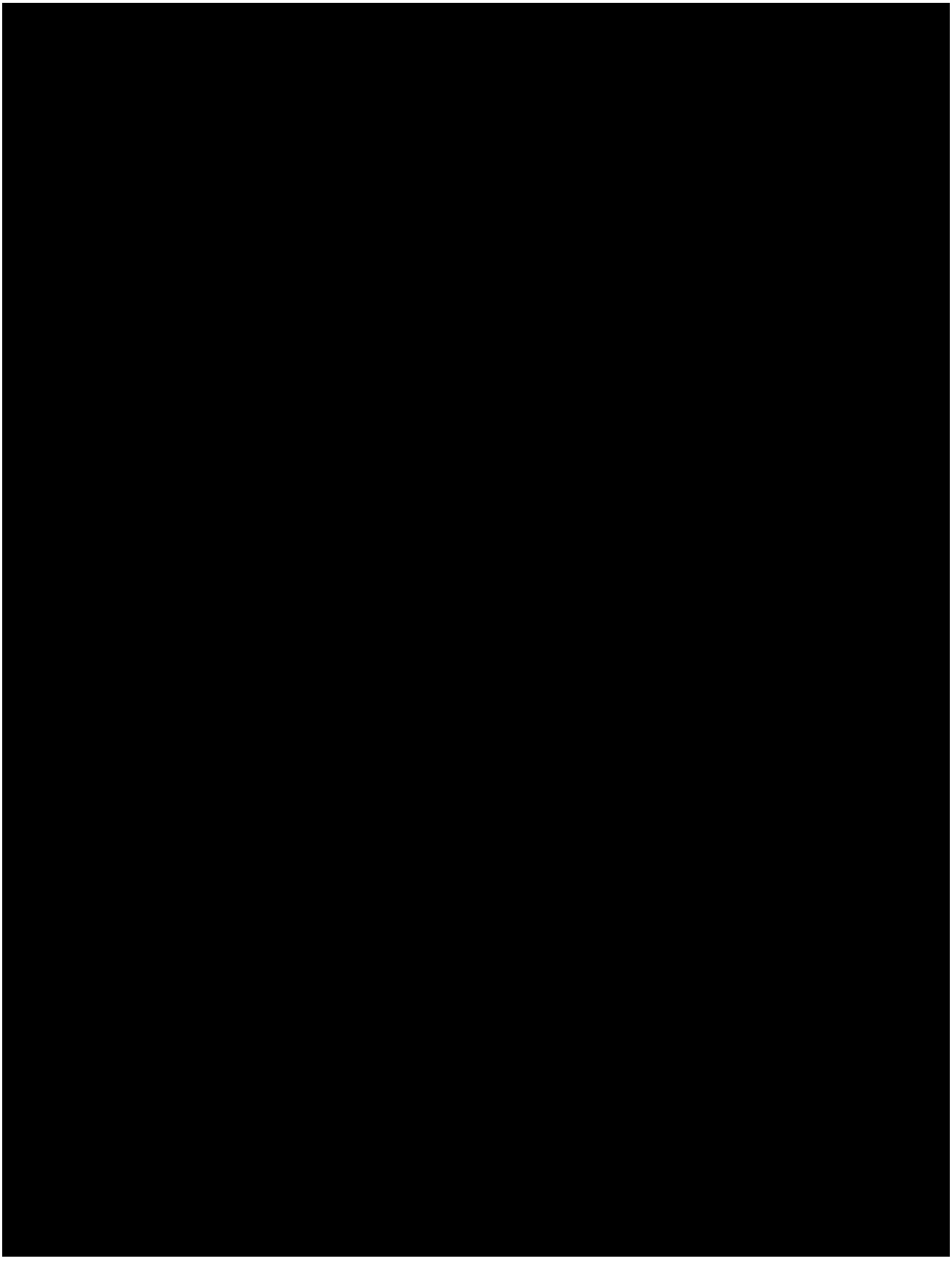
Examples of hydrogen gas accumulation calculations are provided in the following subsections for various packaging configurations and hypothetical contents using the method described in the previous sections and the procedure described in Attachment 7.5-3. The examples are intended to illustrate how to evaluate various configurations and parameters for the contents and packaging and how to perform the calculations.

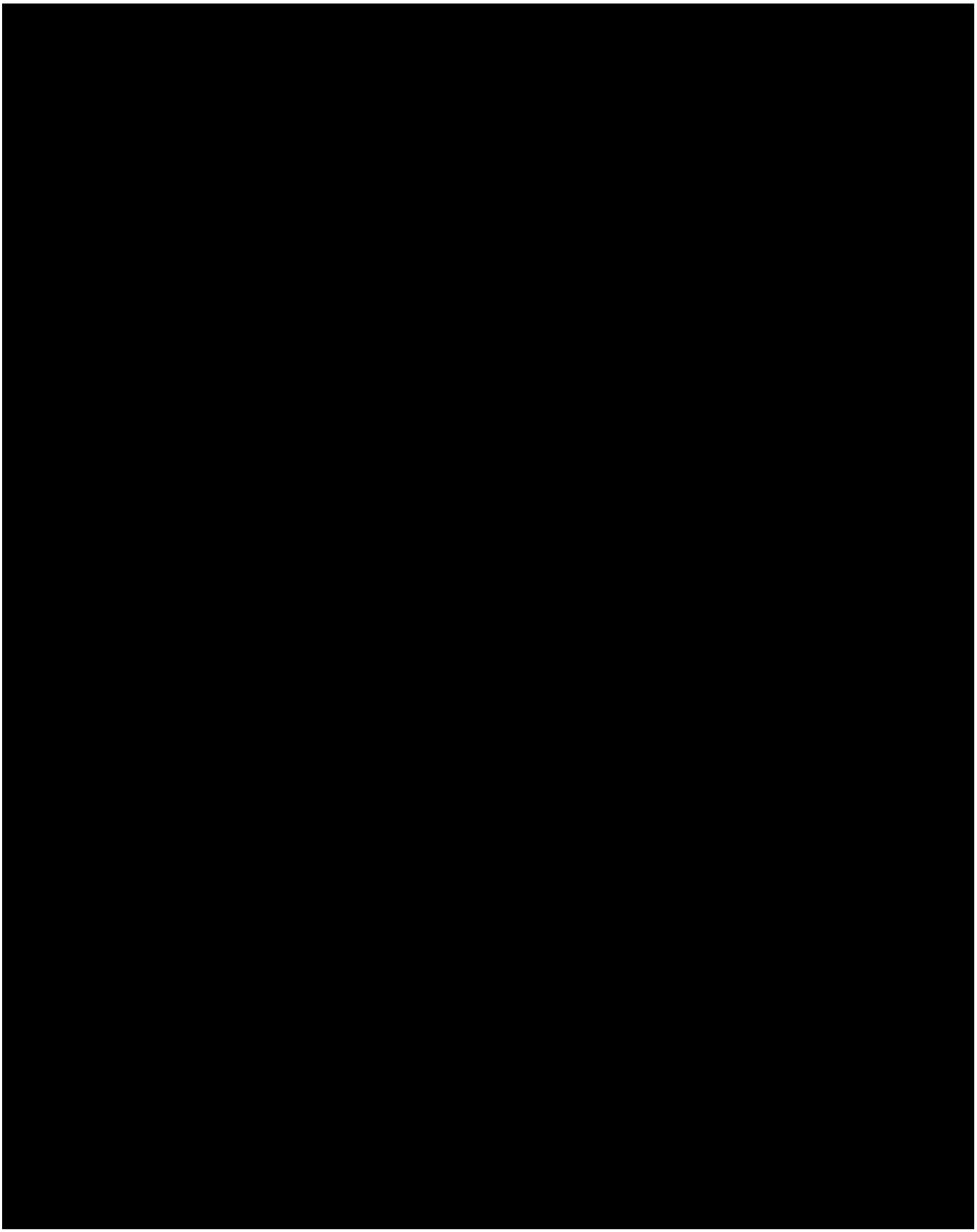


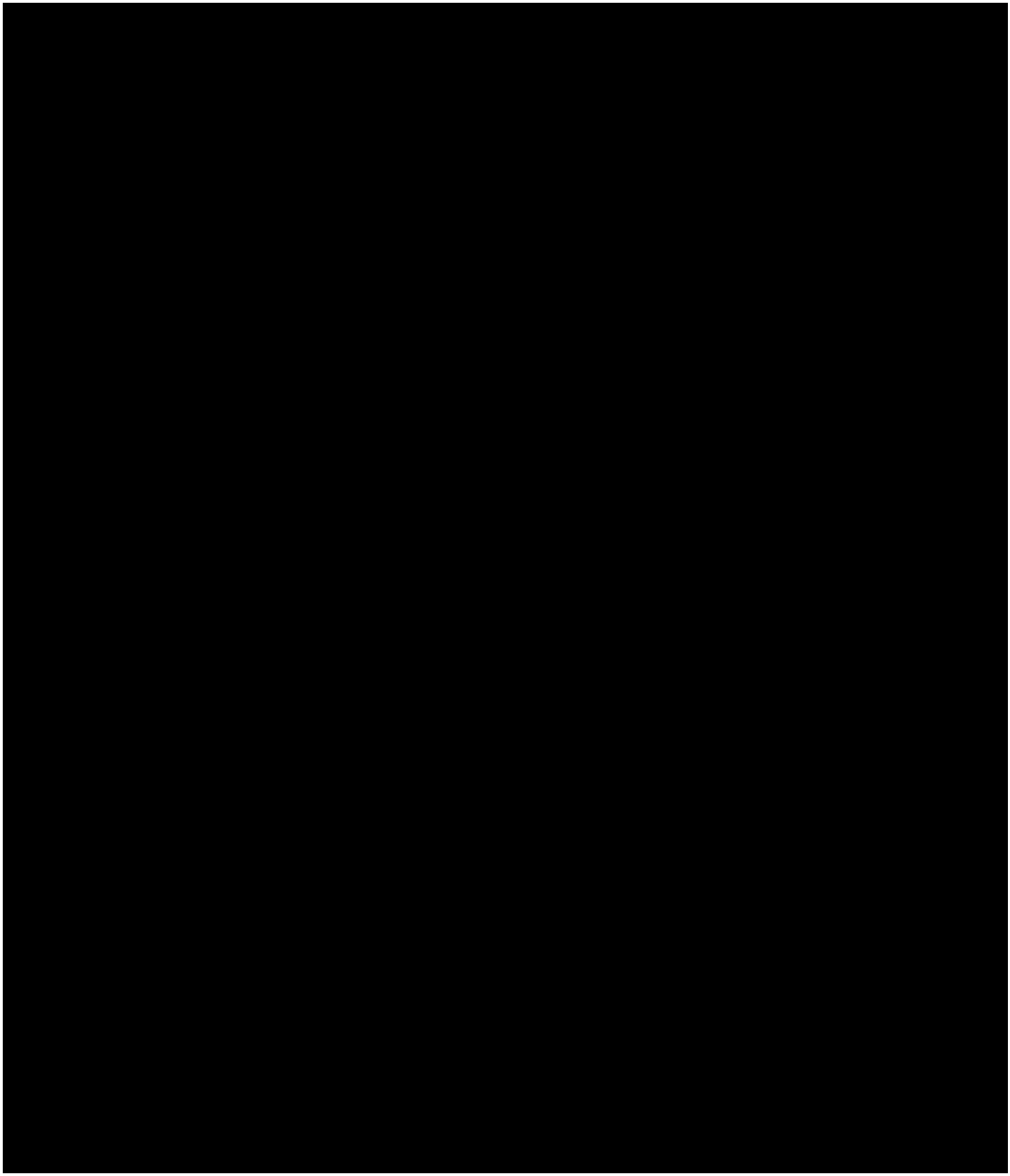


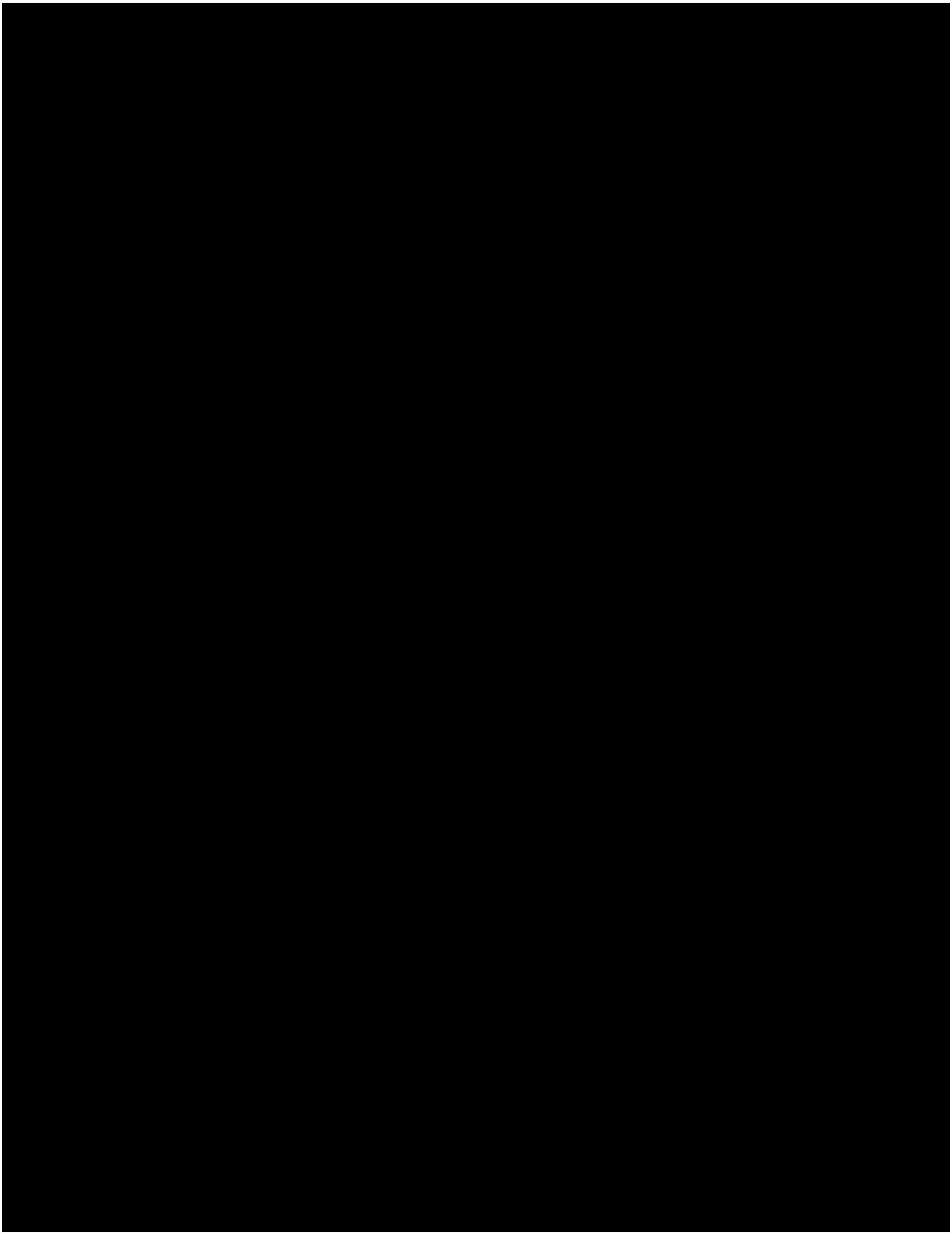


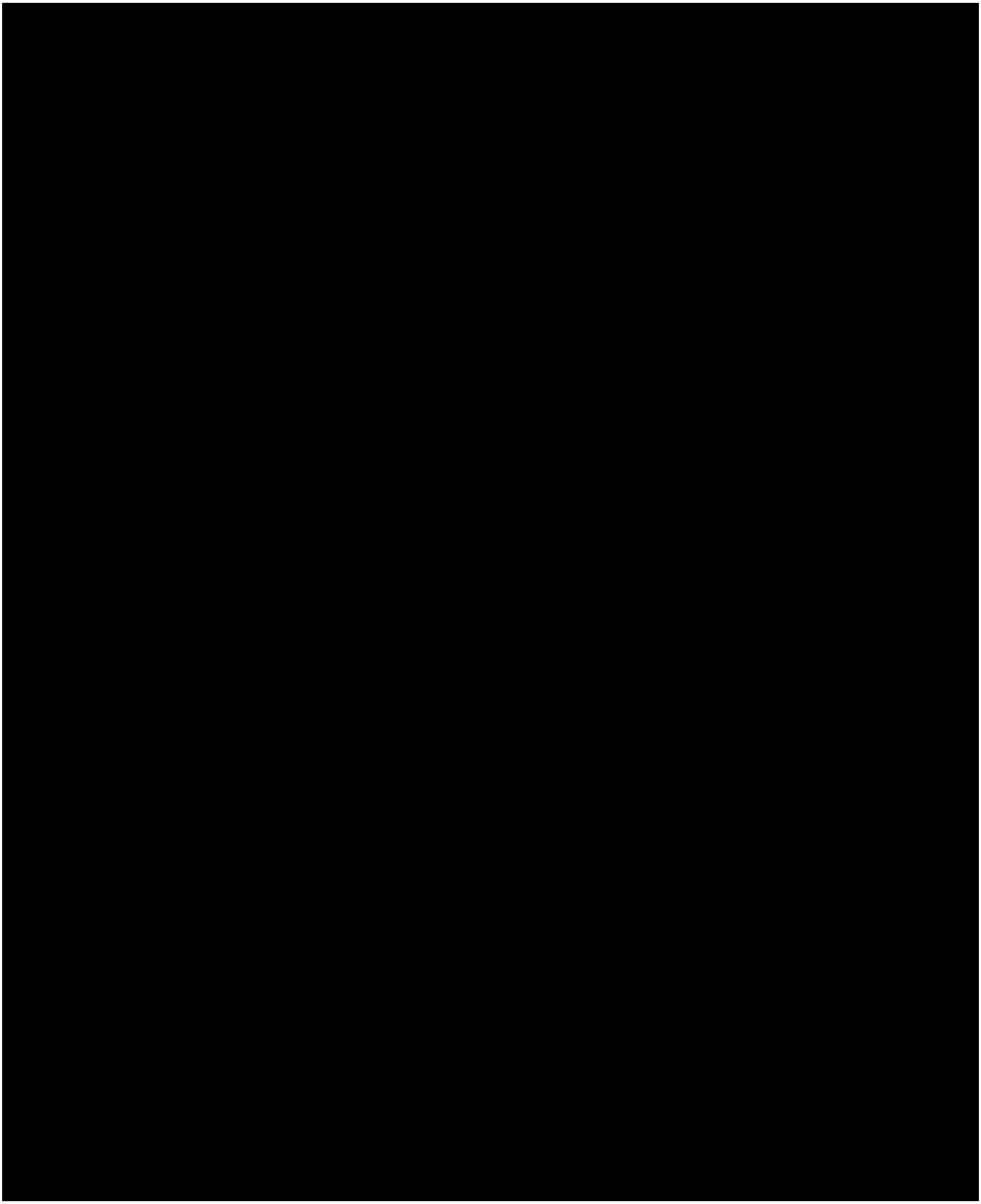


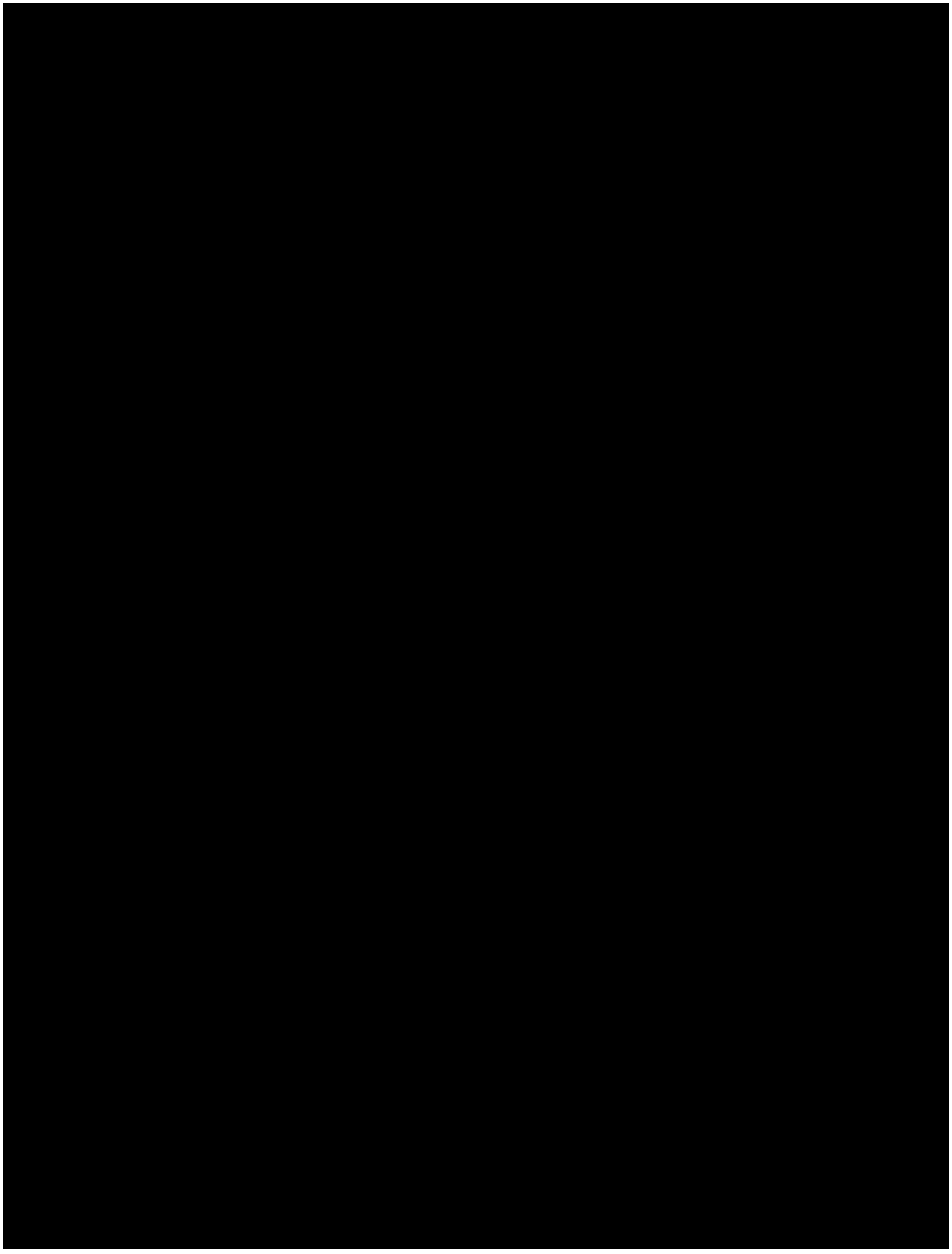


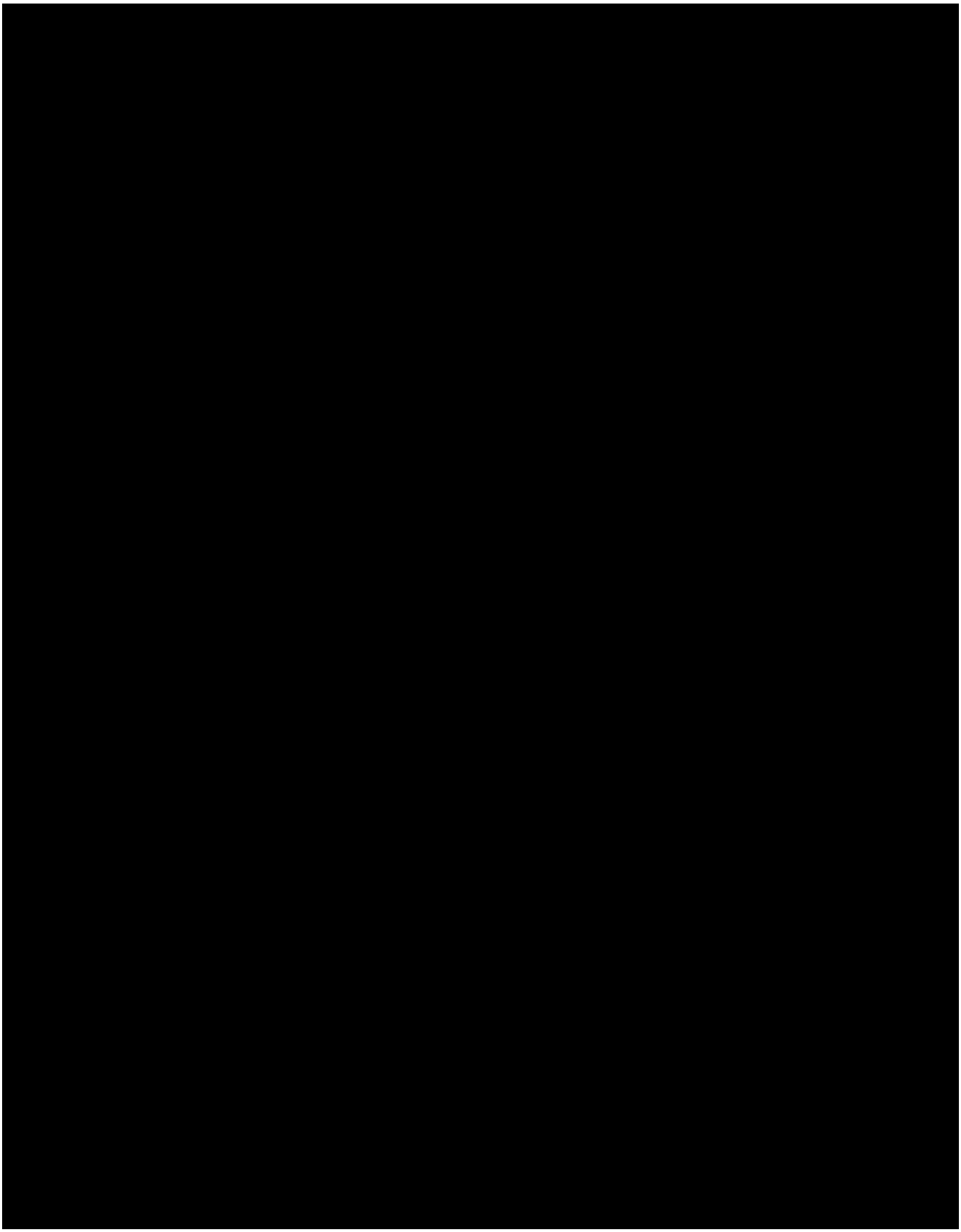












4.5.5 Non-Compliant TRU Waste

As discussed in Section 1.2.2.1, the contents of the package may include a single form of TRU waste with specific items that do not comply with the Waste Acceptance Criteria (WAC) for the Waste Isolation Pilot Project (WIPP) (i.e., non-compliant TRU waste), including:

(1) A maximum of ninety-five (95) standard DOT 2P or 2Q 1-liter aerosol cans filled with compressed gas propellant (Content 1-2A), or

(2) A maximum of 4.4 liters of liquified gas propellant, when the volume of propellant is known based on process knowledge, x-ray, or other interrogation methods, or a maximum of four (4) standard DOT 2P or 2Q 1-liter aerosol containing liquified gas propellant if the amount or type of propellant is unknown (Content 1-2B), or

(3) A maximum of eight (8) full Standard DOT 3E Lecture bottles with known contents of non-flammable gases, or a maximum of one (1) Standard DOT 3E Lecture bottle with unknow contents (Content 1-2C).

Generally, for TRU wastes the only flammable gas of concern is hydrogen generated through radiolysis. The hydrogen concentration limits set for each of these contents limits the quantity of hydrogen or oxygen in the system such that there is no potential for a flammable gas mixture in the CCV. Compliance with these limits is demonstrated via hydrogen concentration calculations, as described in Section 4.5.4.

Non-compliant TRU waste contents are evaluated in the following sections to demonstrate that rupture of all containers of non-compliant TRU waste will not cause internal pressure within the CCV cavity to exceed MNOP (100 psig) or the design basis internal pressure for HAC and that detonation, either prompt or through deflagration-to-detonation transition (DDT), is not credible. Although detonation is shown not to be credible, the structural and thermal effects of a deflagration event in the CCV cavity are evaluated to demonstrate that it will not compromise the containment function of the CCV, based on a defense-in-depth approach.

Section 4.5.5.1 describes the calculation of internal pressure loads for NCT and HAC for each type of non-compliant TRU waste. These calculations demonstrate that the maximum pressure in the CCV during NCT and HAC will not exceed 100 psig and 225 psig, respectively. Compliance with the maximum allowable pressure for the CCV is demonstrated through conservative assumptions and the use of the ideal gas law. Pressure increases from temperature increase of the gas in the CCV, water vapor, radiolysis gases, and release of gases in pressurized containers of noncompliant contents are included.

Potential combustion of non-compliant TRU waste, through deflagration or detonation, is evaluated in Sections 4.5.5.2. In Section 4.5.5.2.1, chemical equilibrium calculations are used to calculate the maximum possible deflagration pressure in the CCV. The maximum deflagration pressure of 161 psig (12.1 bar) from combustion of air and propane plus hydrogen and oxygen from radiolysis is well below the 225 psig HAC design pressure. The quantity of aerosol propellant fuel for a deflagration is significantly less than a single full can (~10% of a can). If more propellant than this quantity is released, the adiabatic flame temperature decreased significantly, and the gaseous mixture leaves the flammable region, eliminating the possibility of combustion. Similarly, for the case of a deflagration event that ruptures additional cans, any significant quantity of propellant released from a ruptured can would smother the flame and immediately reduce the pressure in the CCV to only slightly above the pre-combustion pressure (small change in pressure based on heat and gases released from combustion). The additional

hydrogen-only deflagration cases evaluated demonstrate that with the hydrogen concentration limits imposed on all other TRU waste contents, a combustion event in the CCV would result in pressures well below the pressures for Content 1-2B.

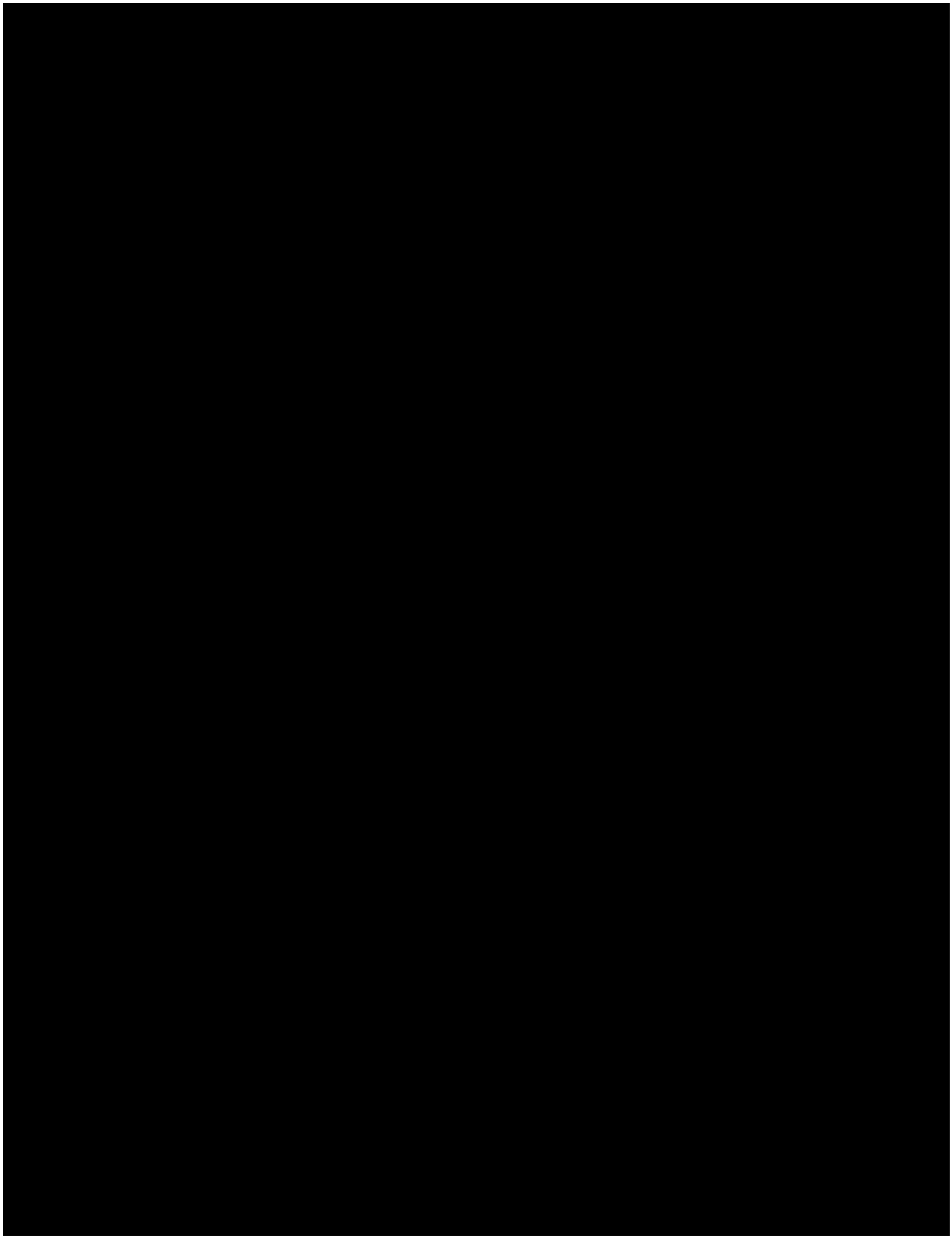
Section 4.5.5.2.2 presents a qualitative assessment of the potential for a detonation-type combustion event in the CCV. There is no possibility of a prompt detonation because the ignition energy of any combustion event would be well below the required energy for prompt detonation. Furthermore, the possibility of detonation through DDT is not credible based on the CCV geometry and composition of the fuel mixture (fuel rich and diluted with helium). Finally, a qualitative assessment of the potential for DDT based on NUREG/CR-4803 concludes that the potential for DDT as "highly unlikely to impossible".

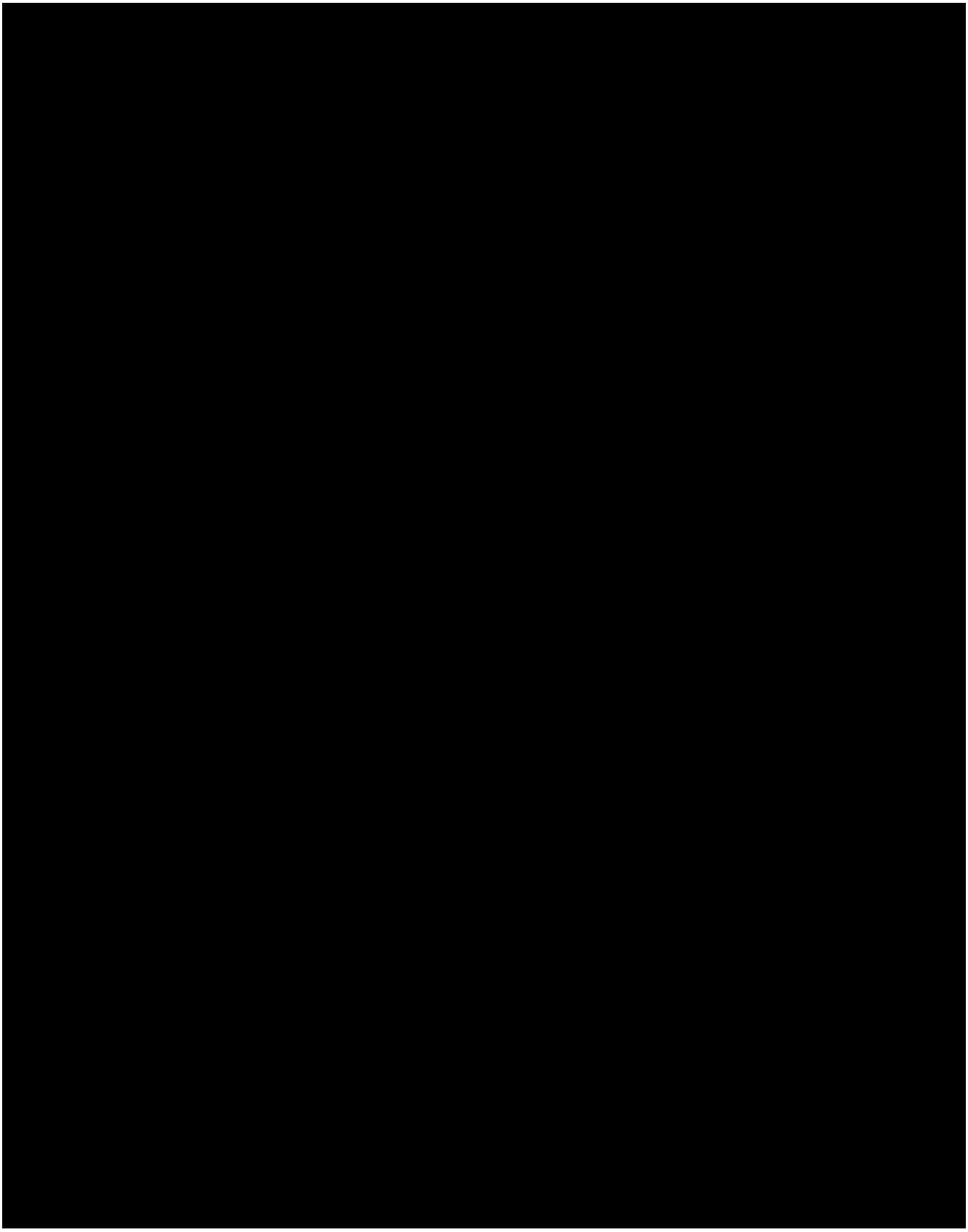
The structural and thermal effects of a hypothetical deflagration event are discussed in Section 4.5.5.3. It is concluded that the structural and thermal effects from a potential deflagration event would not compromise the integrity of the containment system. The deflagration pressure is significantly lower than the HAC design pressure of 225 psig, so the structural effects to the CCV are bounded by the HAC internal pressure evaluation. Additionally, the calculated combustion pressures are independent of the NCT and HAC pressures calculated in Chapter 3, since it is demonstrated that the addition of more aerosol propellant results in a non-flammable gas mixture, eliminating the possibility of a combustion event. Based on the maximum quantity of energy released from a potential combustion event, the increase in temperatures of the O-ring seals and CCV body would be minimal and well below the respective material temperature limits, so the thermal effects of the combustion event would not compromise the integrity of the containment system.

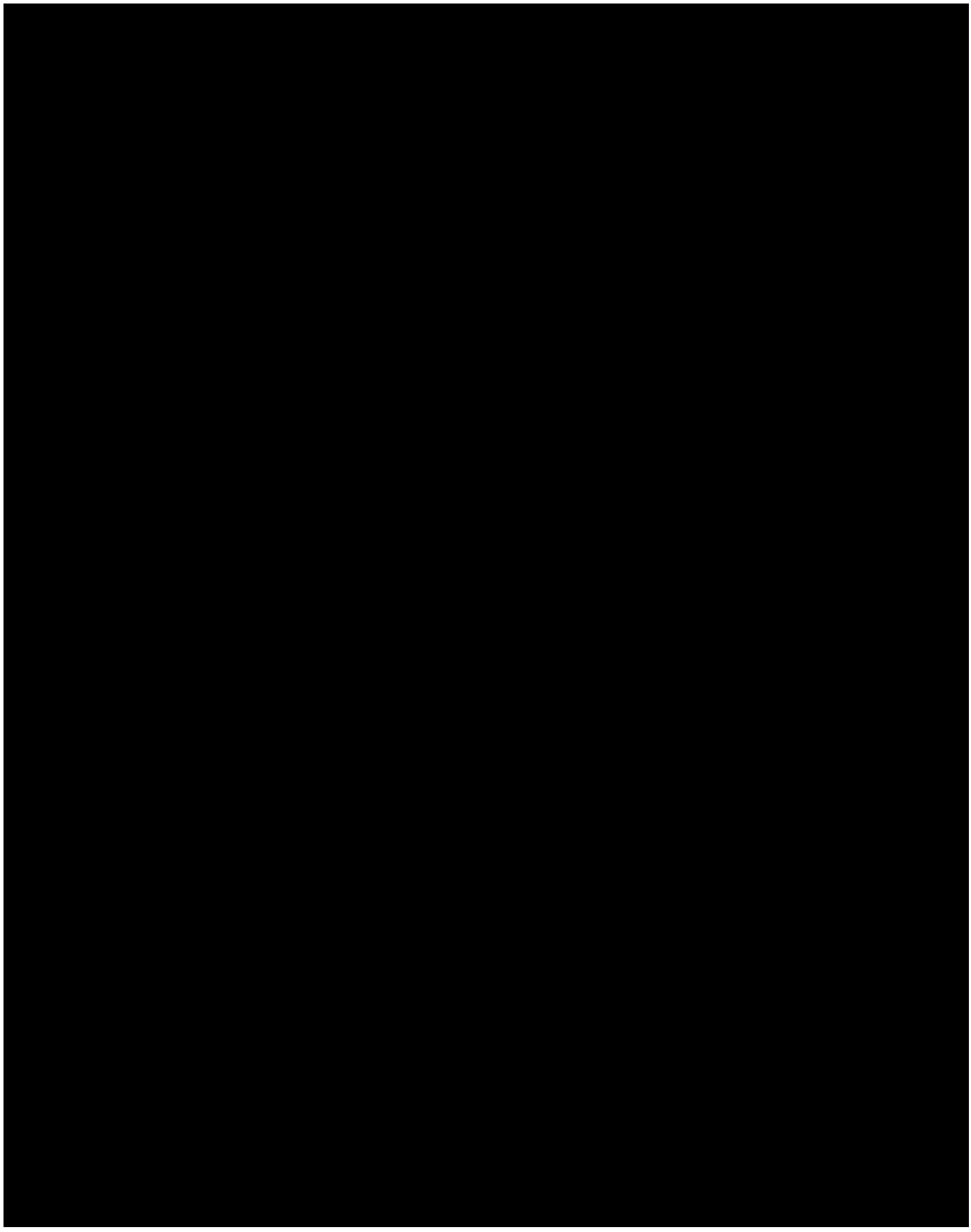
4.5.5.1 Pressure Calculations for Non-Compliant TRU Waste

The pressure calculations in Sections 3.3.2 and 3.4.3.2 are for compliant TRU waste and irradiated fuel wastes (Contents 1-1 and 2-1) only. This appendix provides the pressure calculations for non-compliant TRU wastes (Contents 1-2A, 1-2B, and 1-2C). For each calculation, the increase in pressure from the release of compressed gases is accounted for by adding an additional term to the TRU waste pressure calculations from Sections 3.3.2 and 3.4.3.2. For each non-compliant TRU waste content type, the additional pressure term is calculated as the ratio of the number of moles of gas released from the pressurized containers to the initial number of moles of gas in the CCV. For all non-compliant contents, the initial number of moles of gas in the CCV is calculated based on the free volume in the cavity. The free volume is calculated based on the total CCV cavity volume (V_{CCV}) minus the volume taken up the TRU waste container (V_C) and the shoring (V_S). The volume of the empty CCV cavity is 639 L. The volume of a TRU waste container is typically a 55-gallon drum (208 L) but can be

smaller or larger, and as large as 110 gallons (416 L)







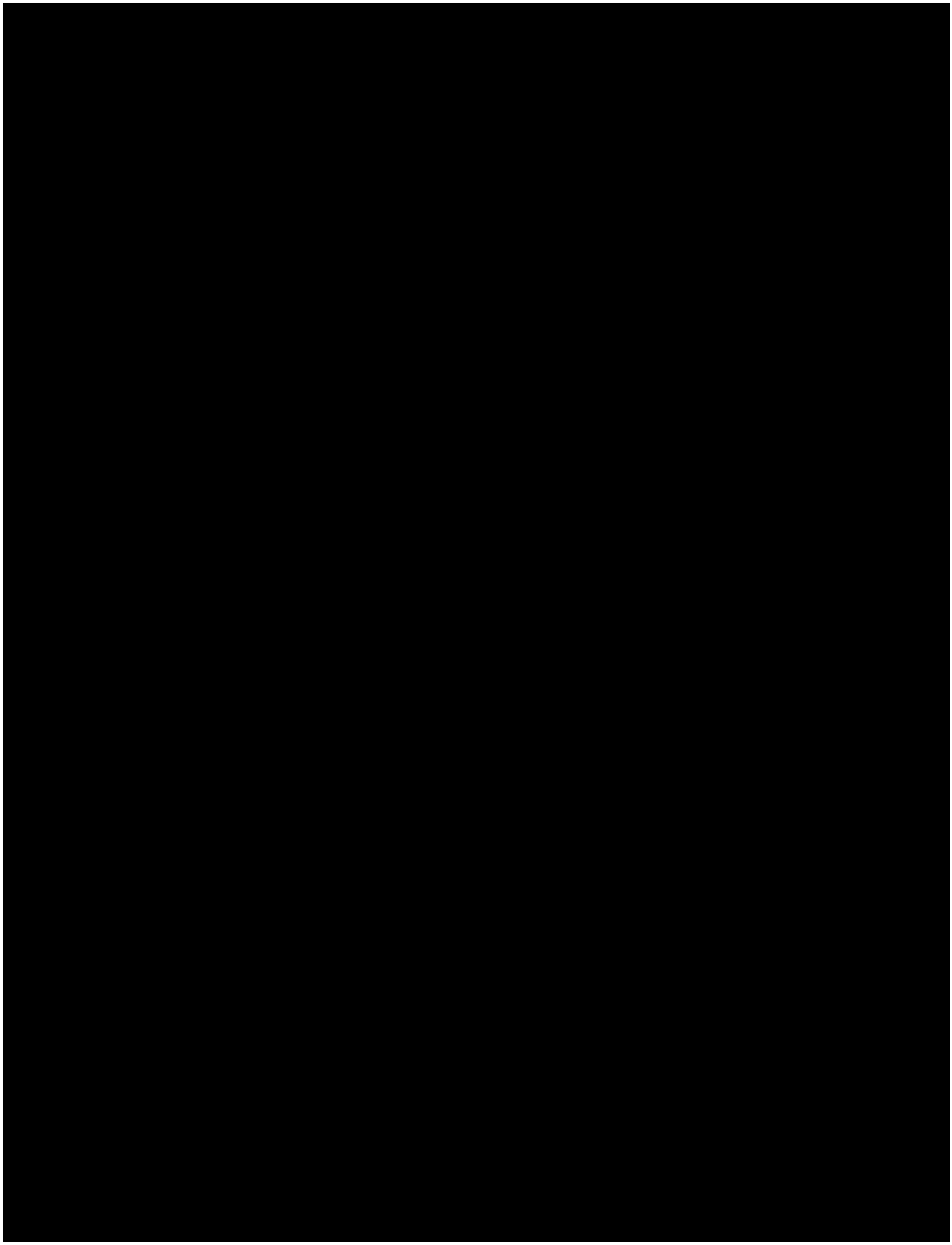


Table 4.5-1 LOC Values for Flammable Gases

[redacted]

Table 4.5-2 TRU Waste Contents - Flammability Limits

[redacted]

Table 4.5-3 TRU Waste Maximum Hydrogen G-Values and Activation Energies

[redacted]

Table 4.5-4 TRU Waste Minimum Hydrogen Release Rates

Table 4.5-5 Non-Compliant TRU Waste Maximum Pressures

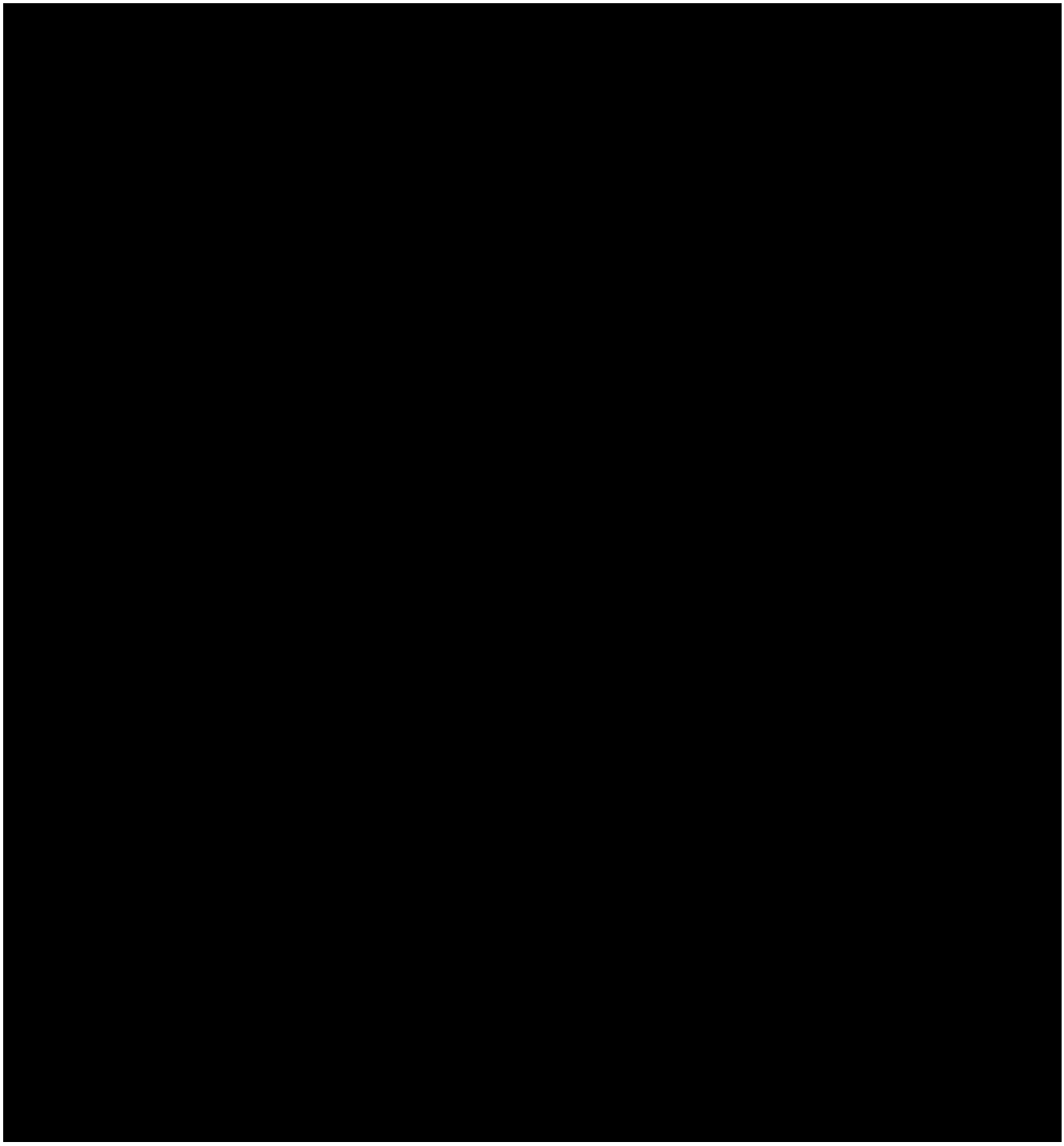
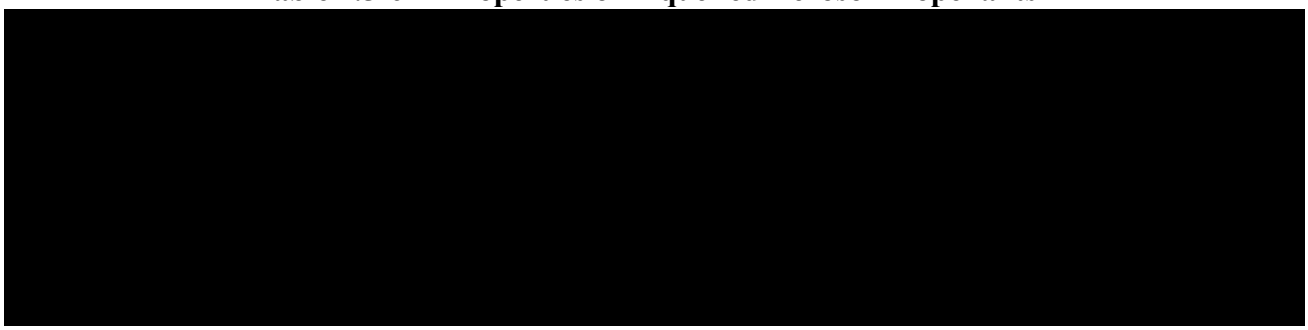
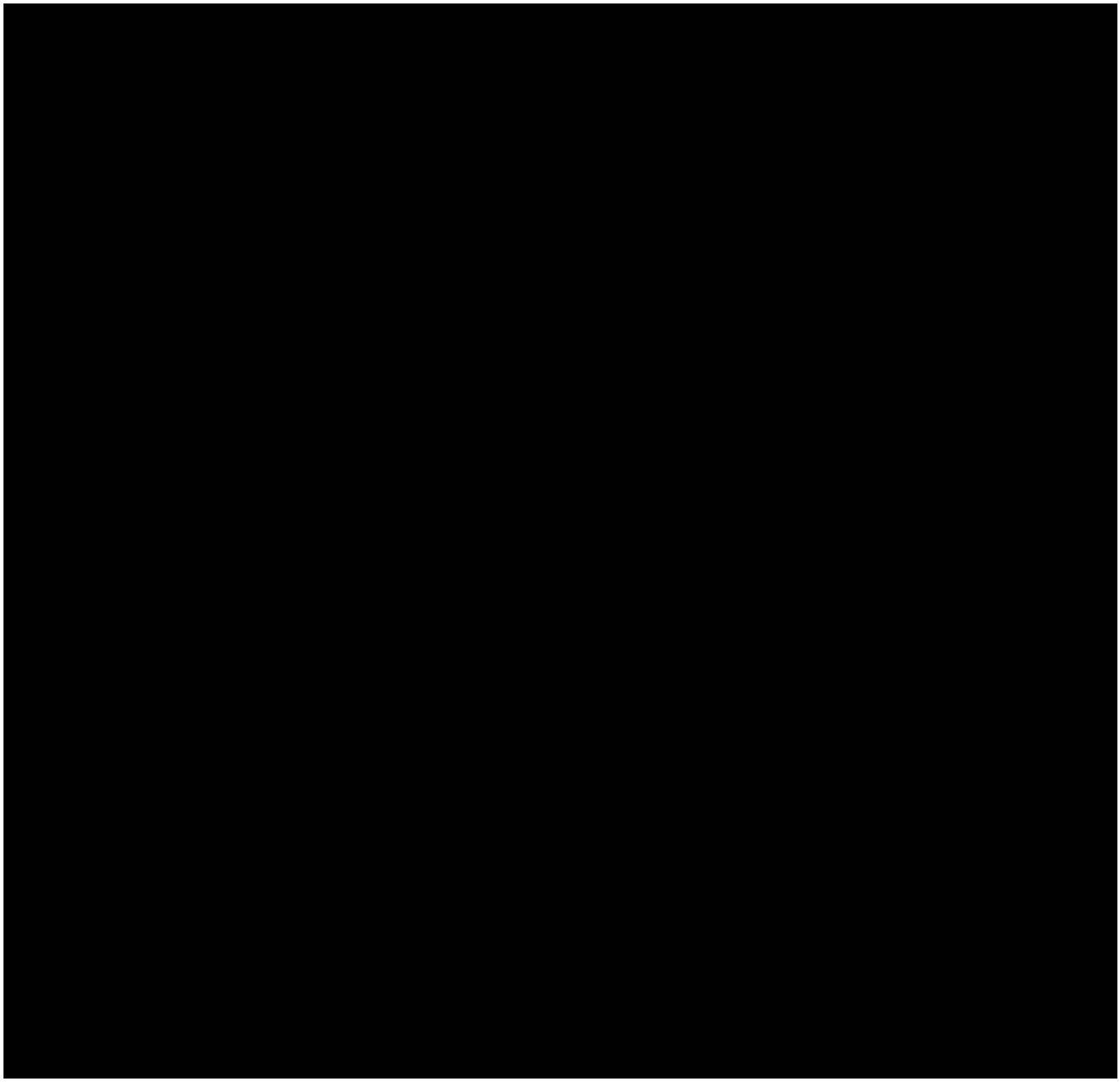


Table 4.5-6 Properties of Liquefied Aerosol Propellants



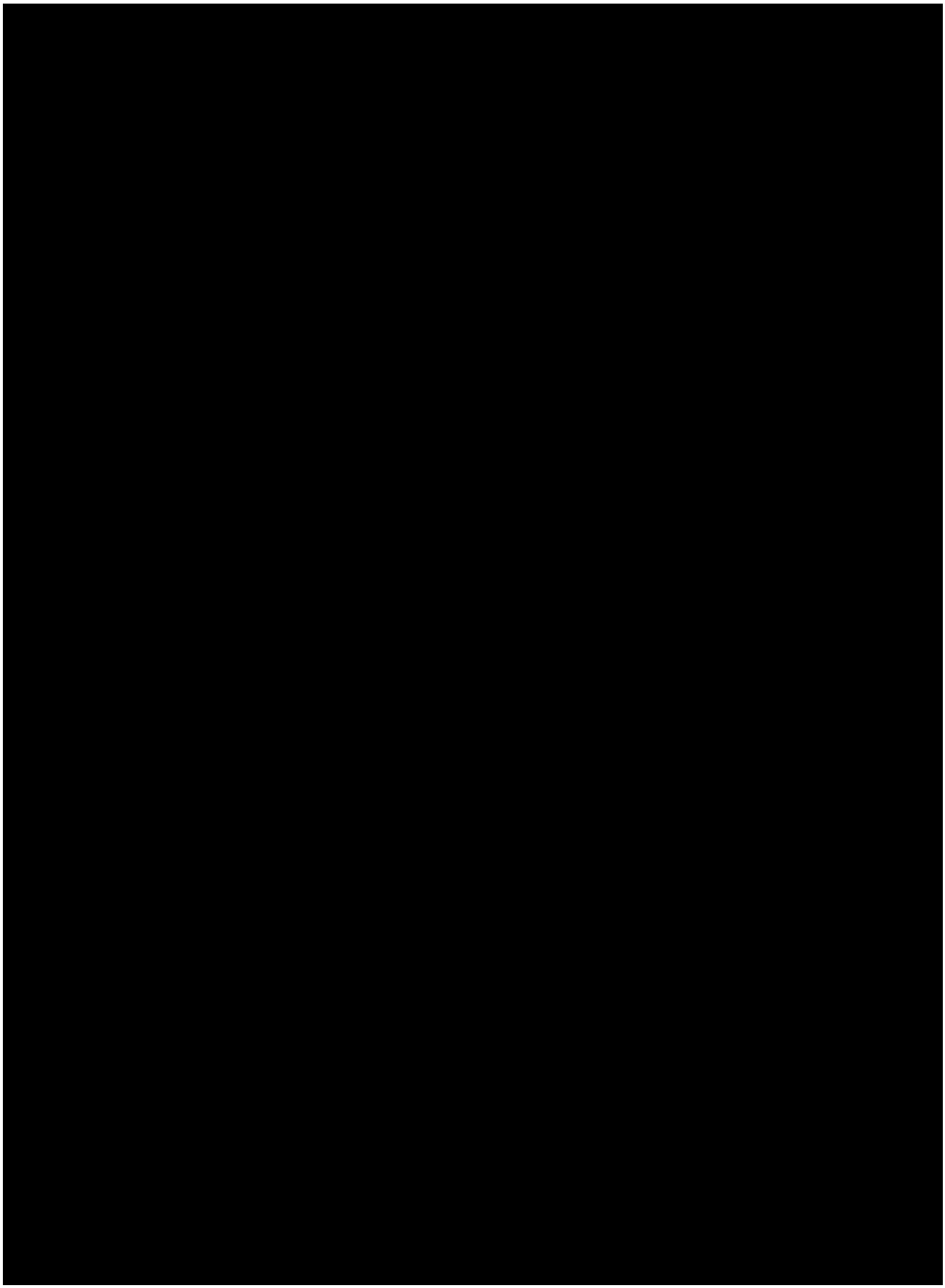
4.5.5.2 Combustion Analysis of Non-Compliant TRU Waste

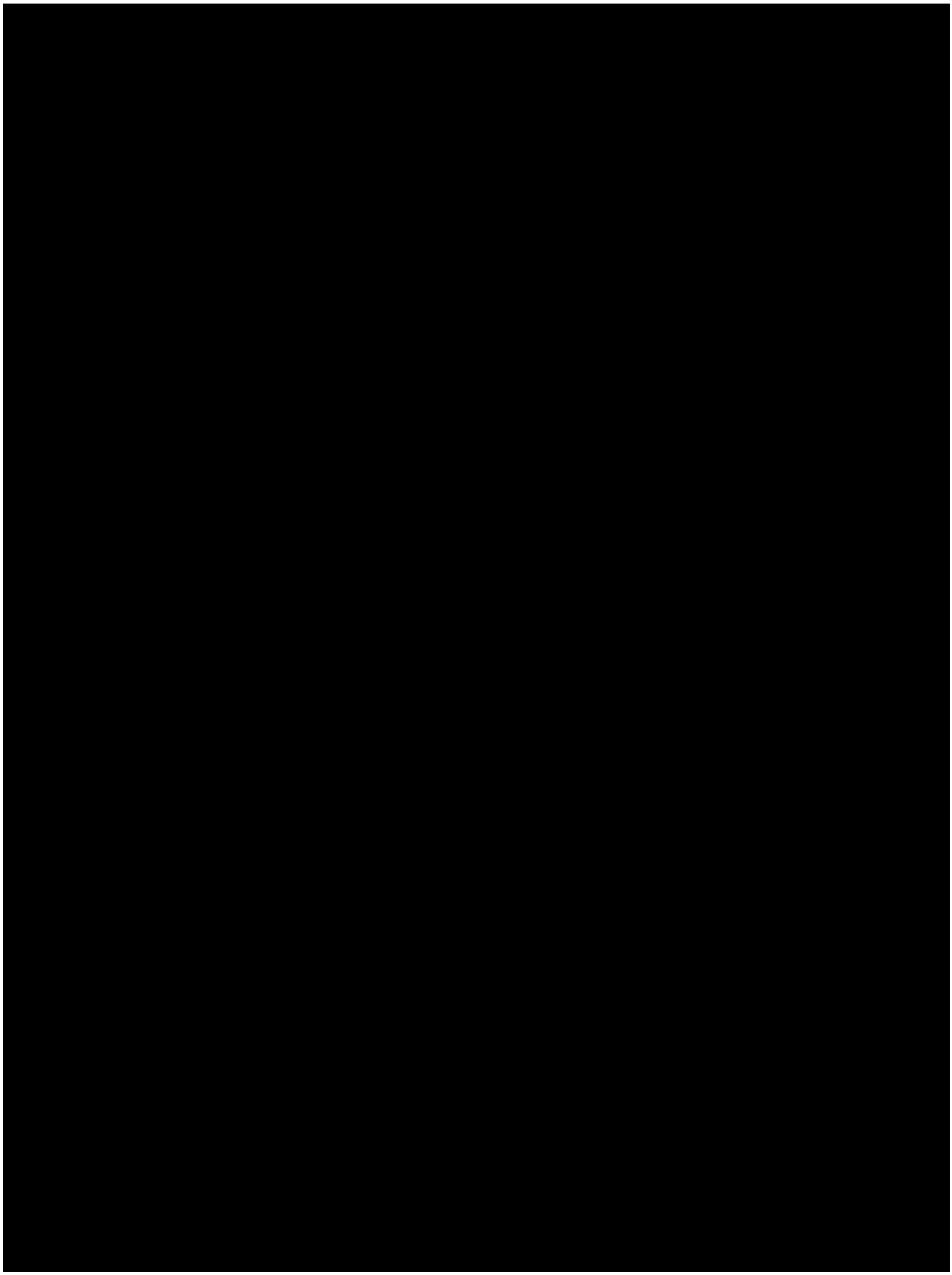
The potential effects of a combustion event in the CCV from a mixture of flammable gases (hydrogen or aerosol propellants) are discussed in this section. Limitations on each content are set to restrict the gaseous mixture in the CCV to a non-flammable mixture. For TRU waste, the only flammable gas of concern is hydrogen generated through radiolysis. The hydrogen concentration limits set for each of these contents limits the quantity of hydrogen or oxygen in the system such that there is no potential for a flammable gas mixture in the CCV. Compliance with these limits is demonstrated via hydrogen concentration calculations, as outlined in Section 4.5.4. For TRU waste containing aerosol cans with liquefied gas propellants (Content 1-2B), such as propane and butane, additional flammability risks are considered.

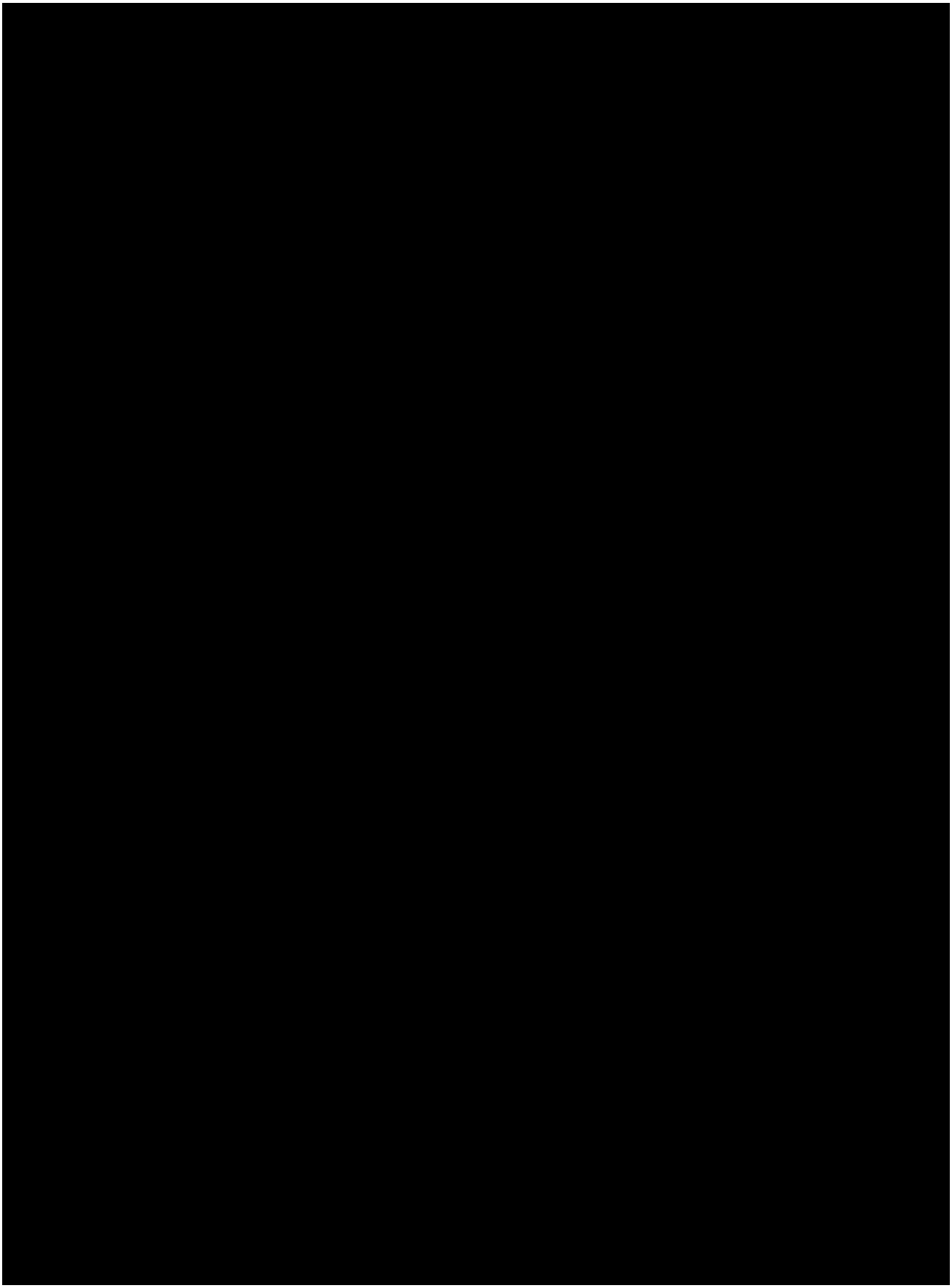


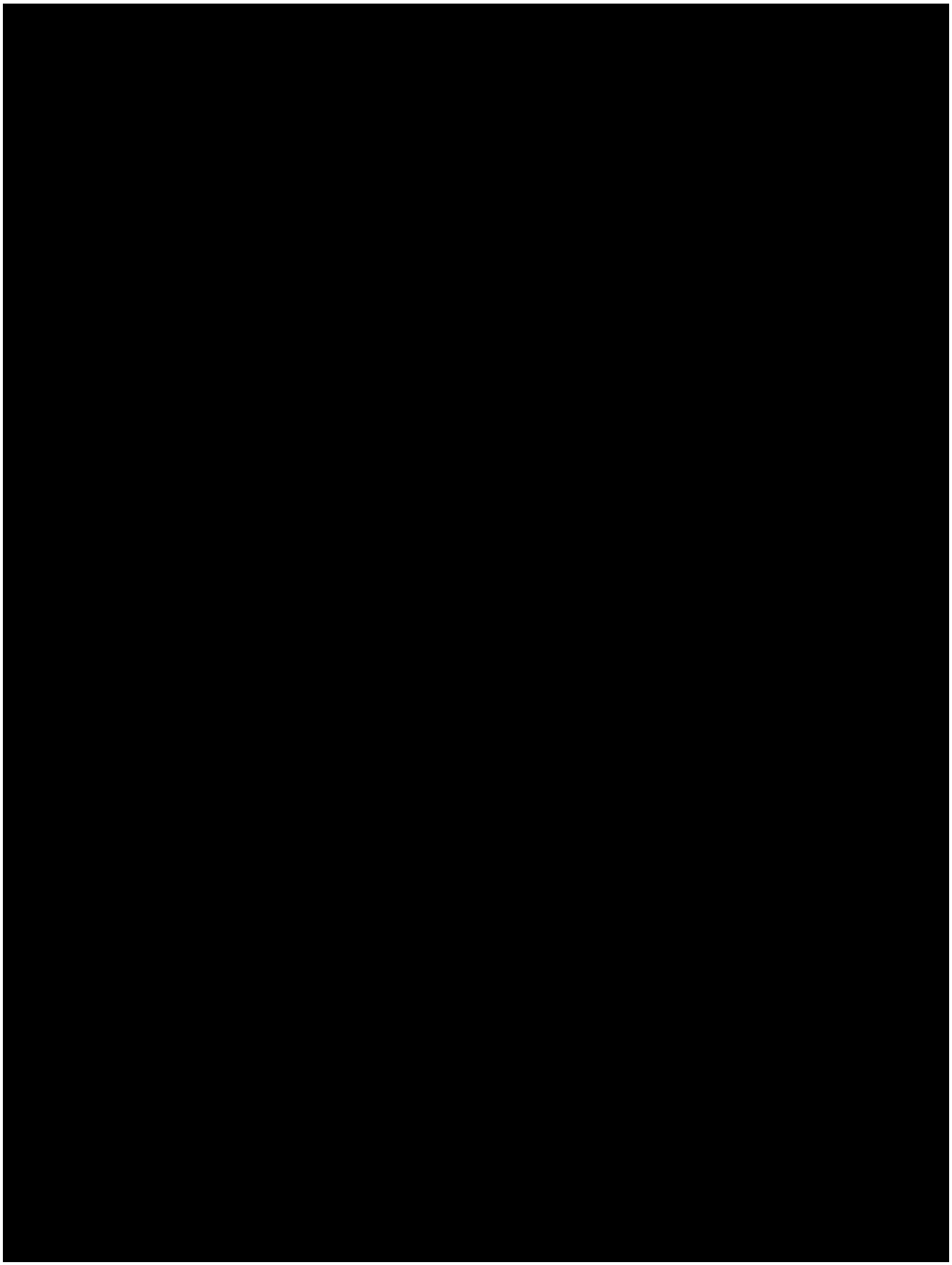
4.5.5.2.1 Potential Deflagration of Non-Compliant TRU Waste

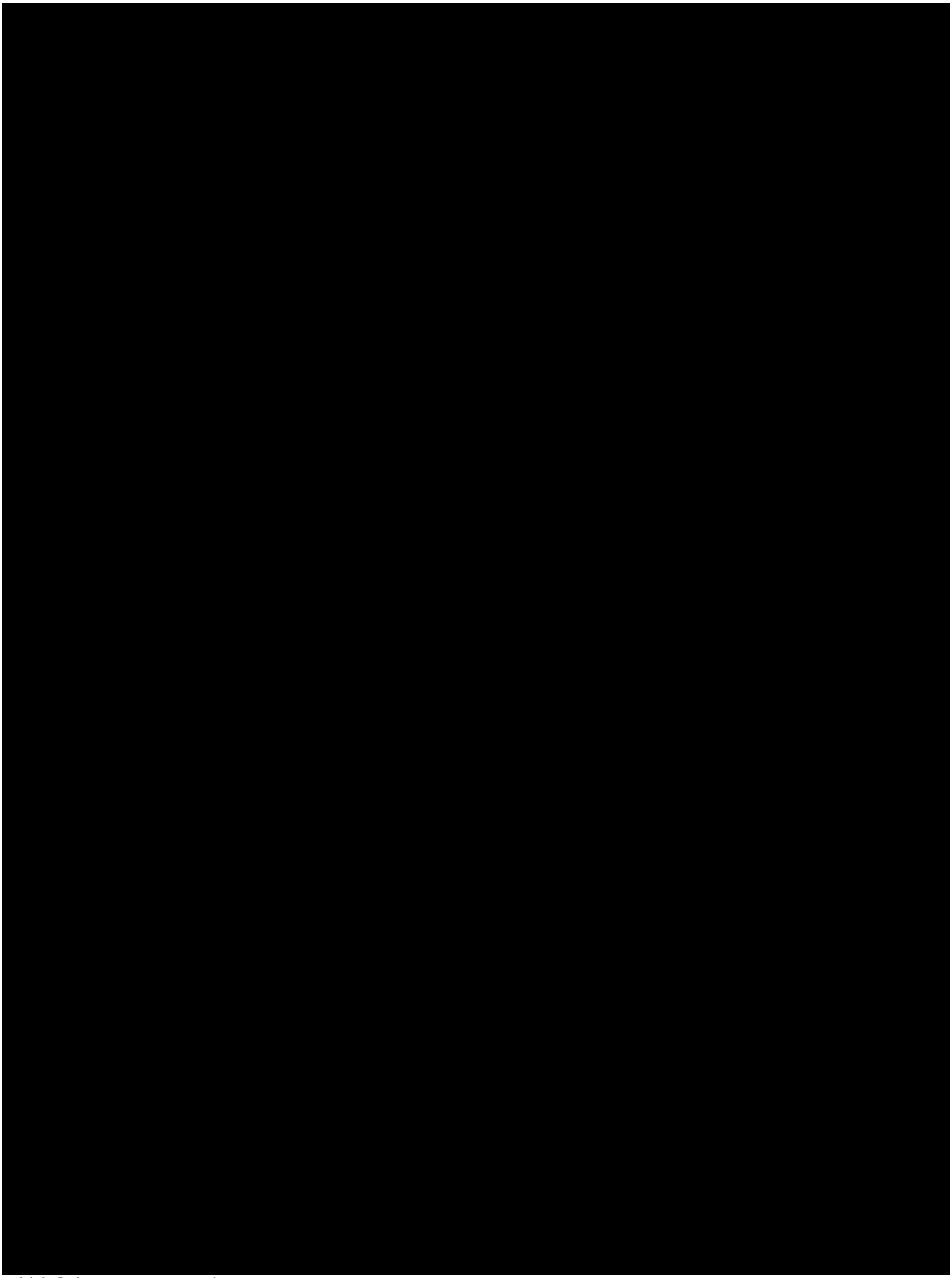
[redacted]

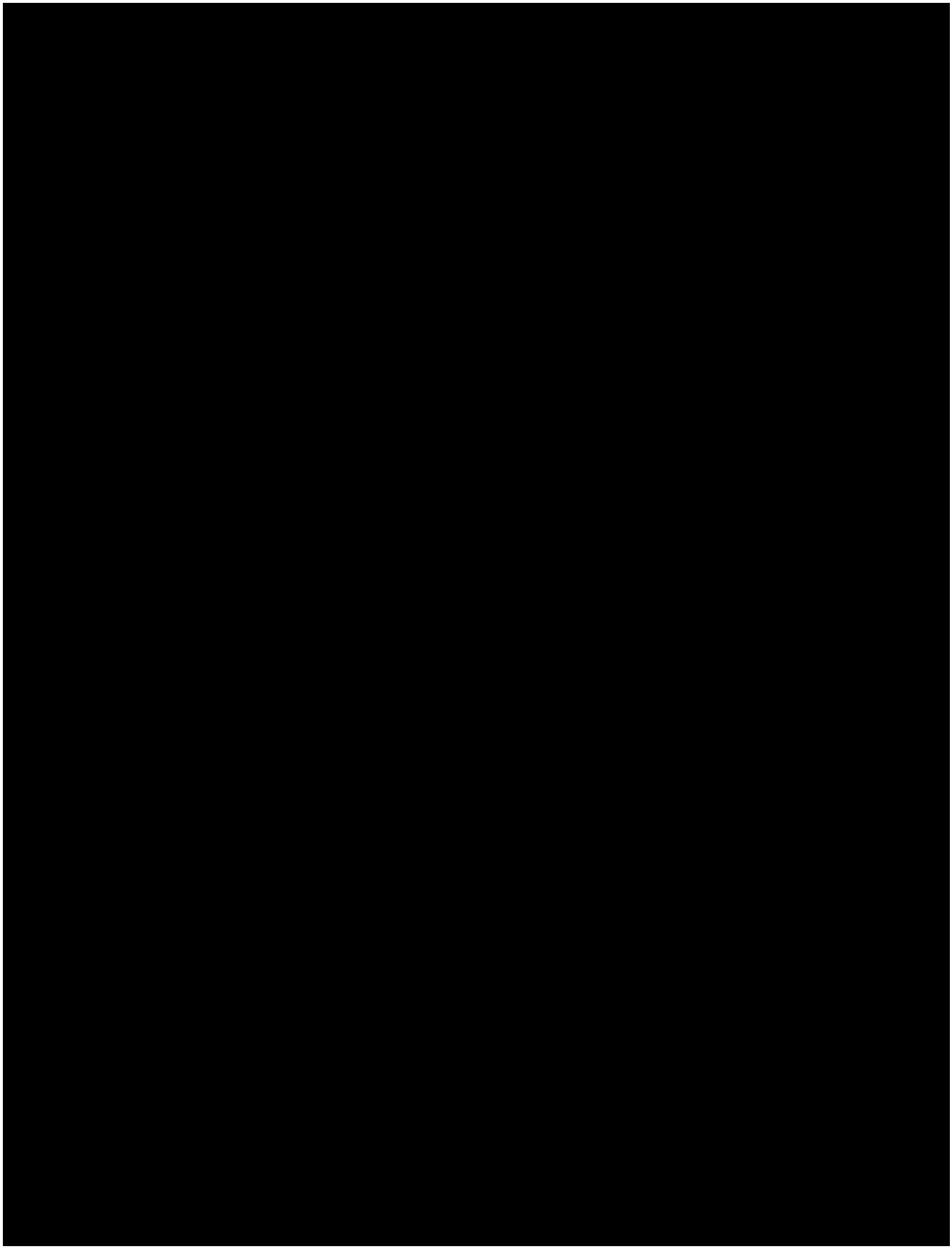


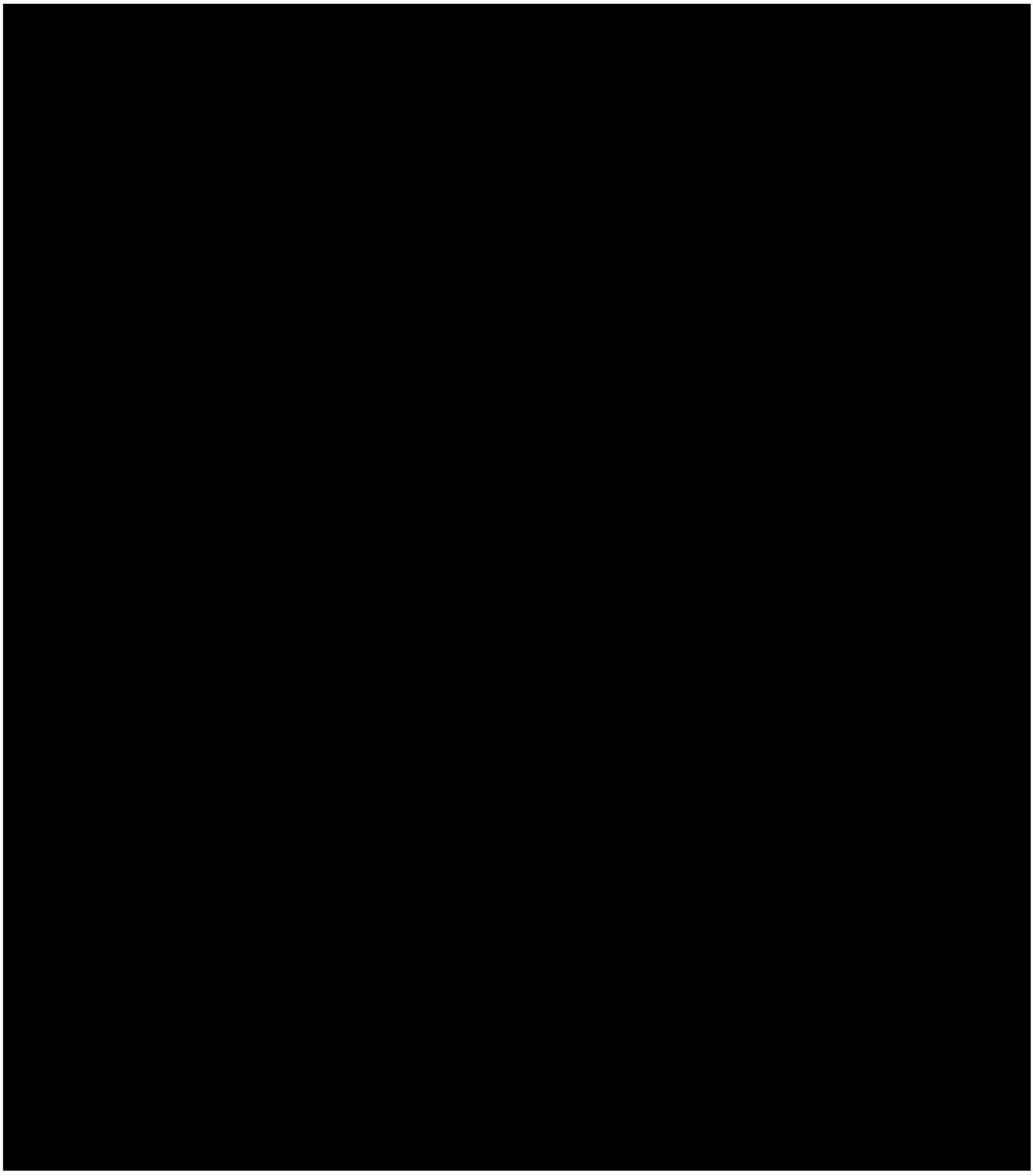












4.5.5.3 Effects of Combustion of Non-Compliant TRU Waste

The thermal and structural effects of a combustion event on the CCV containment boundary are based on a deflagration of a flammable gas mixture. Both structurally and thermally, the effects

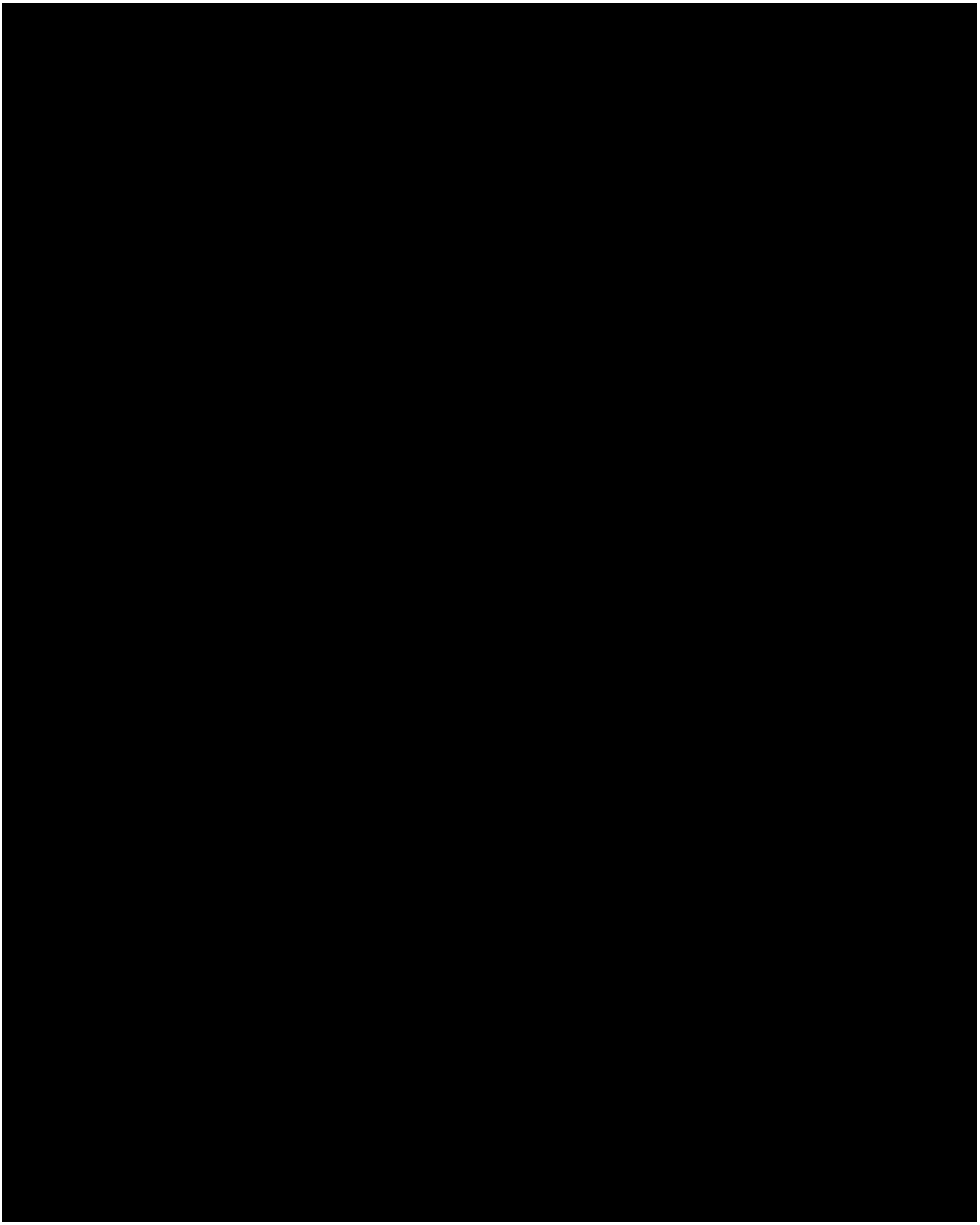
of a flammable gas deflagration are bounding of the burning of any flammable materials in the TRU waste container (papers, plastics, etc.).

4.5.5.3.1 Structural Effects

[redacted]

4.5.5.3.2 Thermal Effects

[redacted]



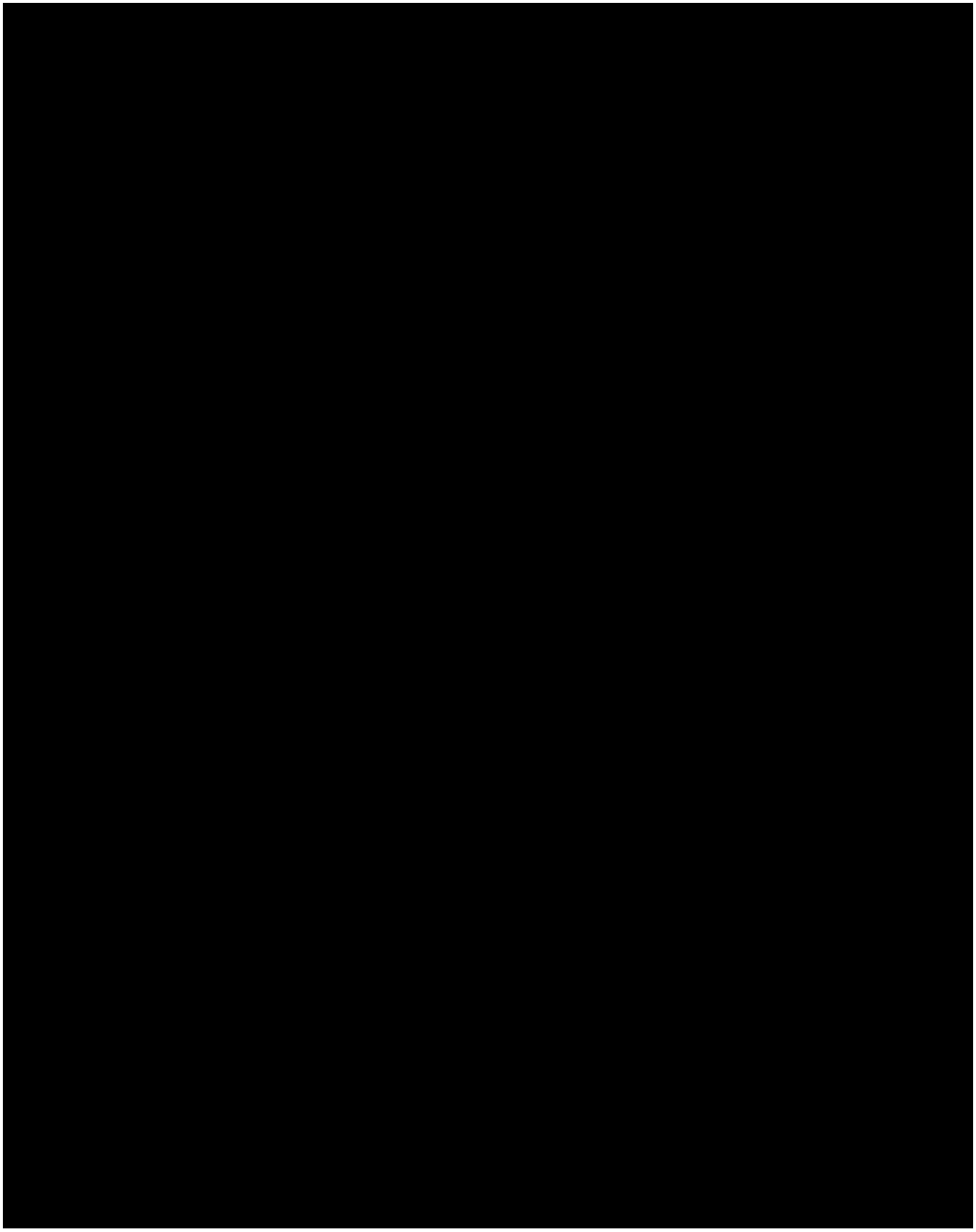


Table 4.5-7 Aerosol Propellant and Hydrogen Characteristics

[redacted]

Table 4.5-8 Air/Helium Gas Mixtures

[redacted]

Table 4.5-9 - Flammability Limits for Hydrogen Gas and Propellant Mixtures

[redacted]

Table 4.5-10 - Radiolysis Gas Cases - Deflagration Parameters/Results

[redacted]

Table 4.5-11 - Hydrogen Gas Cases - Deflagration Parameters/Results

[redacted]

Table 4.5-12 - NUREG/CR-4803 Mixture Classification

[redacted]

Table 4.5-13 - Energy Released from Hydrocarbon Fuel Burn

[redacted]

Table 4.5-14 - CCV/Seal Combustion Temperature Change Calculation

Figure 4.5-1 - Hydrocarbon Propellant Combustion Pressures

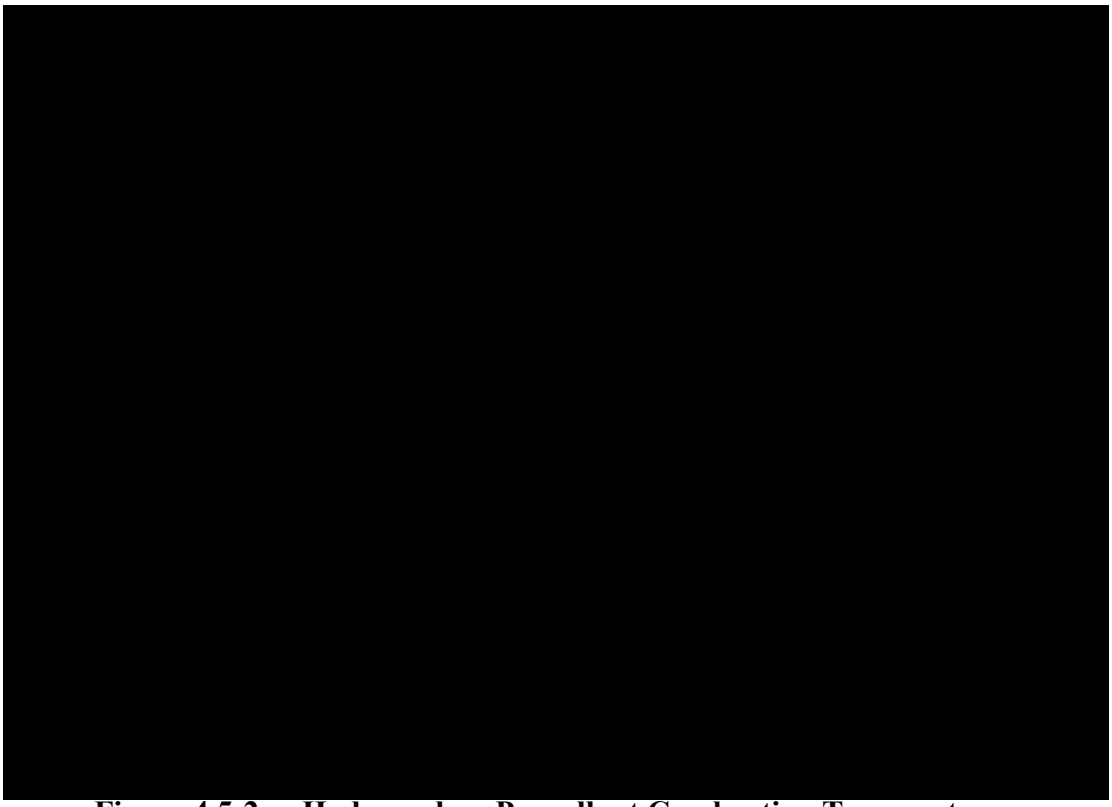


Figure 4.5-2 - Hydrocarbon Propellant Combustion Temperatures

Figure 4.5-3 - Inert Gas Case Combustion Pressures

Figure 4.5-4 - Inert Gas Case Combustion Temperatures

Figure 4.5-5 - Radiolysis Gas Case Combustion Pressures

Figure 4.5-6 - Radiolysis Gas Case Combustion Temperatures

Figure 4.5-7 - Hydrogen Combustion Pressures

Figure 4.5-8 - Hydrogen Combustion Temperatures

Figure 4.5-9 - [redacted] Results Matrix

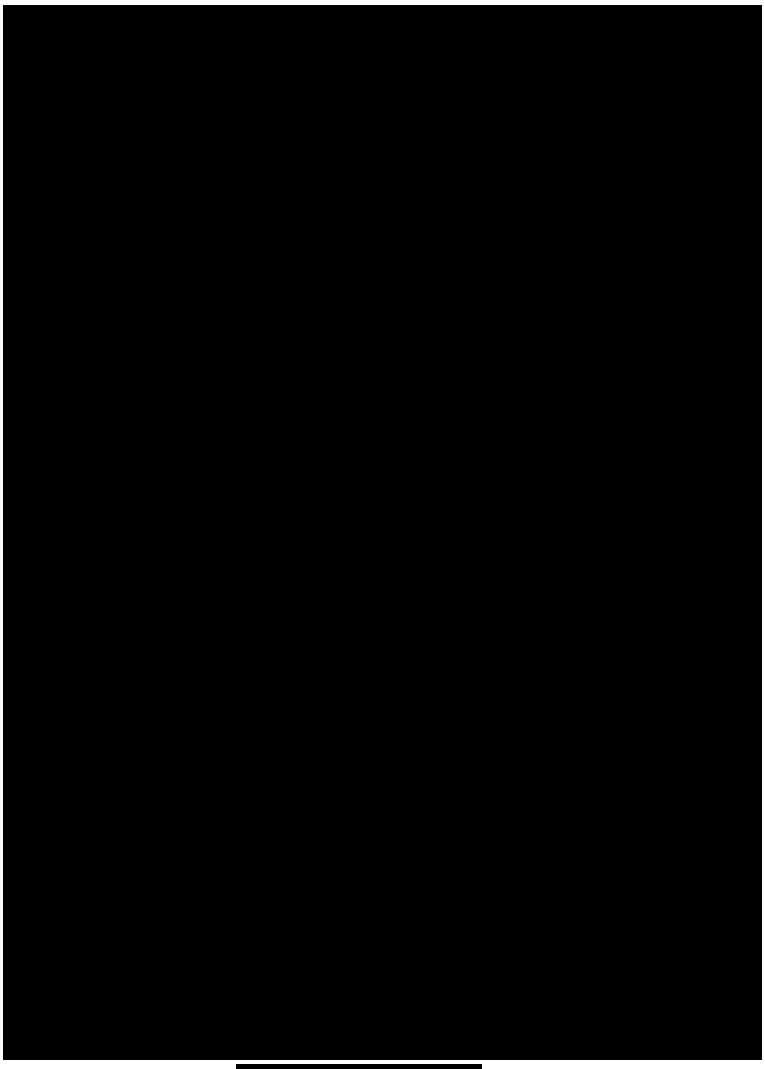


Figure 4.5-10 - [redacted] Results Matrix

Chapter 5
Shielding Evaluation

Table of Contents

5 SHIELDING EVALUATIOtN 5-1

5.1 Description of Shielding Design 5.1-1
5.1.1 Shielding Design Features 5.1-1
5.1.2 Summary of Maximum Radiation Levels 5.1-2

5.2 Source Specification 5.2-1
5.2.1 Gamma Source 5.2-1
5.2.2 Neutron Source 5.2-2

5.3 Shielding Model 5.3-1
5.3.1 Configuration of Source and Shielding 5.3-1
5.3.2 Material Properties 5.3-3

5.4 Shielding Evaluation 5.4-1
5.4.1 Methods 5.4-1
5.4.2 Input and Output Data 5.4-5
5.4.3 Flux-to-Dose Rate Conversion 5.4-5
5.4.4 External Radiation Levels 5.4-5

5.5 Appendices 5.5-1
5.5.1 References 5.5-1
5.5.2 OSV Allowable Manufacturing Under Thickenss 5.5-2
5.5.3 SIA Shielding Analysis 5.5-6
5.5.4 Irradiated CANDU Fuel and Hardware Waste Shielding Analysis 5.5-20

List of Figures

Figure 5.3-1 [redacted] Shielding Model – Package Geometry 5.3-8
Figure 5.3-2 [redacted] Shielding Model – NCT Source Configuration 5.3-9
Figure 5.3-3 [redacted] Shielding Model – HAC Source Configurations 5.3-9
Figure 5.3-4 [redacted] Shielding Model – Axial Tally Locations 5.3-10
Figure 5.3-5 [redacted] Shielding Model – Side Tally Locations 5.3-10
Figure 5.4-1 [redacted] 5.4-9
Figure 5.5-1 OSV Under Thickness Model Changes – All Neutron Cases and Side Photon Cases 5.5-5
Figure 5.5-2 OSV Under Thickness Model Changes – Top and Bottom Photon Cases 5.5-5
Figure 5.5-3 [redacted] Model 5.5-17
Figure 5.5-4 [redacted] Model 5.5-17
Figure 5.5-5 [redacted] Model 5.5-18
Figure 5.5-6 [redacted] Source Locations 5.5-19
Figure 5.5-7 G1 Fuel Bundle Design 5.5-29
Figure 5.5-8 CANDU Fuel Case Shielding Model 5.5-29
Figure 5.5-9 G1 Hardware Case Shielding Models (L – Zirc / M – Steel / R – Inconel) 5.5-30
Figure 5.5-10 G1 Combined Hardware Case Shielding Model 5.5-30

List of Tables

Table 5.1-1 Package Shielding Design Features 5.1-4
Table 5.1-2 Co-60 NCT Dose Rates Example Calculation – Bare Cask 5.1-4
Table 5.1-3 Co-60 HAC Dose Rates Example Calculation – Bare Cask 5.1-4
Table 5.1-4 Cf-252 NCT Dose Rates Example Calculation – Bare Cask 5.1-5
Table 5.1-5 Cf-252 HAC Dose Rates Example Calculation – Bare Cask 5.1-5
Table 5.2-1 Photon Source Energy Group Structure 5.2-3
Table 5.2-2 Neutron Source Energy Group Structure 5.2-4
Table 5.3-1 Primary [redacted] Model Package Dimensions 5.3-4
Table 5.3-2 [redacted] Shielding Model – Tally Locations 5.3-5
Table 5.3-3 Material Compositions 5.3-6
Table 5.3-4 [redacted] Material Definitions 5.3-7
Table 5.4-1 ANSI/ANS-6.1.1 1977 Flux-to-Dose Conversion Factors 5.4-13
Table 5.4-2 [redacted] NCT Gamma Dose Rate Summary 5.4-14
Table 5.4-3 [redacted] NCT Neutron Dose Rate Summary 5.4-15
Table 5.4-4 [redacted] HAC Gamma Dose Rate Summary 5.4-16
Table 5.4-5 [redacted] HAC Neutron Dose Rate Summary 5.4-17
Table 5.4-6 [redacted] Cf-252 Spectra 5.4-18
Table 5.4-7 Cf-252 2-meter Dose Rate Calculation 5.4-19
Table 5.5-1 OSV Under Thickness Dose Rate Results 5.5-4
Table 5.5-2 SIA Design Directional Thickness 5.5-8
Table 5.5-3 [redacted] NCT Gamma Dose Rate Summary 5.5-9
Table 5.5-4 [redacted] NCT Neutron Dose Rate Summary 5.5-10
Table 5.5-5 [redacted] NCT Gamma Dose Rate Summary 5.5-11
Table 5.5-6 [redacted] NCT Neutron Dose Rate Summary 5.5-12
Table 5.5-7 [redacted] NCT Gamma Dose Rate Summary 5.5-13
Table 5.5-8 [redacted] NCT Neutron Dose Rate Summary 5.5-14
Table 5.5-9 [redacted] HAC Gamma Dose Rate Summary 5.5-15
Table 5.5-10 [redacted] HAC Neutron Dose Rate Summary 5.5-16
Table 5.5-11 CANDU Fuel Content Restrictions 5.5-24
Table 5.5-12 CANDU Fuel Content Maximum Radiation Levels 5.5-24
Table 5.5-13 CANDU Fuel Neutron Source 5.5-25
Table 5.5-14 CANDU Fuel Photon Source 5.5-26
Table 5.5-15 G1 Hardware Exposure History 5.5-26
Table 5.5-16 G1 Hardware Cobalt Impurities and Cobalt-60 Content 5.5-27
Table 5.5-17 CANDU Fuel and G1 Hardware [redacted] Content Material Compositions 5.5-27
Table 5.5-18 G1 Hardware Case Activities 5.5-28
Table 5.5-19 CANDU Fuel and G1 Hardware Case Dose Rate Results 5.5-28

This page intentionally left blank.

5 SHIELDING EVALUATION

The OPTIMUS®-H packaging is designed to provide adequate shielding to ensure that dose rates do not exceed the NCT and HAC limits specified in 10 CFR 71.47(b), 10 CFR 71.51(a)(1) and 10 CFR 71.51(a)(2), respectively. This chapter outlines the shielding design of the packaging and the shielding analysis that demonstrates compliance with the dose rate limits of 10 CFR 71.

This page intentionally left blank.

5.1 Description of Shielding Design

5.1.1 Shielding Design Features

The packaging design is comprised of three primary components: the cask containment vessel (CCV), the outer shield vessel (OSV), and the impact limiter system (ILS). The assembly of these components is shown in Figure 1-1. Narrative descriptions of these components are provided below in Sections 5.1.1.1 through 5.1.1.3. The design features of the packaging that are credited for radiation shielding are listed in Table 5.1-1.

The minimum thickness of the OSV bottom plate, shell, and lid are all specified as 1/8-inch less than the nominal thickness. Limited local under thickness in the OSV is permitted based on the analysis in Appendix 5.5.2. The CCV body and lid are composed of ASME plate and forging components. The permissible variation under the specified thickness for ASME plate material is 0.01 inches [5.2].

5.1.1.1 CCV Shielding Design Features

The CCV is the inner vessel that serves as the primary containment boundary of the packaging. [redacted]

5.1.1.2 OSV Shielding Design Features

The OSV [redacted] that serves as the primary shielding component of the package and provides impact protection to the CCV from a puncture. The OSV body and lid are casted as solid monolithic structures to ensure no reduction of the shielding effectiveness of the component. The drain port in the OSV is filled with a SS plug during transport, to eliminate radiation streaming through the port.

5.1.1.3 Impact Limiter Shielding Design Features

The ILS is comprised of two impact limiters with a [redacted] outer skin filled with polyurethane foam, to provide impact protection for the package and protect the OSV lid from a puncture. The [redacted] shells of the ILS are credited for the radiation shielding from the top and bottom of the package. Any radiation shielding provided by the polyurethane foam or outer skin of the ILS is neglected.

5.1.1.4 Shield Insert Assemblies

The packaging may be configured with three different Shield Insert Assembly (SIA) designs that provide additional shielding for increased maximum isotopic activity limits: [redacted] the SIA lid is lowered into position on the top end of the SIA body and captured by the CCV lid. The shielding analysis for the SIAs is provided in Appendix 5.5.3.

5.1.2 Summary of Maximum Radiation Levels

A package containing IFW (i.e., LEU or CANDU fuel) or FMC contents must be transported solely as an exclusive use shipment, whereas a package containing TRU waste contents may be shipped on a nonexclusive use conveyance or under exclusive use controls.

For nonexclusive use shipments 10 CFR 71.47(a) limits the dose rate at any point on the surface of the package to 2 mSv/h (200 mrem/h) and the TI (i.e., the maximum dose rate in mSv/h × 100 (or mrem/h) at 1-meter from the package external surface) to 10 for NCT.

For exclusive use shipments in an open transport vehicle (e.g., an open flatbed trailer), 10 CFR 71.47(b) specifies the following limits for NCT dose rates:

- 2 mSv/h (200 mrem/h) at any point on the external surface of the package or any point on the outer surface of the vehicle*
- 0.1 mSv/h (10 mrem/h at any point 2-meters from the outer lateral surface of the vehicle or any point 2 meters from the vertical planes projected by the outer edges of the vehicle (excluding the underside of the vehicle)
- 0.02 mSv/h (2 mrem/h) in any normally occupied space (e.g., tractor cab), except that this provision does not apply to private carriers, if exposed personnel under their control wear radiation dosimetry devices in conformance with 10 CFR 20.1502

For exclusive use shipments in a closed transport vehicle (e.g., a Conestoga trailer or an ISO container) where the package is secured within the vehicle so that its position remains fixed during transportation and there are no loading or unloading operations between the beginning and end of the transportation, 10 CFR 71.47(b)(1) limits the dose rate at any point on the external surface of the package to 10 mSv/h (1000 mrem/h).

* The outer surface of the vehicle includes the top and underside of the vehicle; or in the case of a flat-bed style vehicle, at any point on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load or enclosure, if used, and on the lower external surface of the vehicle.

10 CFR 71.51(a)(2) limits the dose rate at 1-meter from the package surface to 10 mSv/h (1000 mrem/h) for HAC.

The transport vehicle surface (i.e., trailer), 2-meter, and cab (occupied position) dose rates are only calculated from the side of the package, as the package is only transported in the upright position.

Because the contents of the package are variable, and the final isotope inventory is different for each TRU waste content or irradiated fuel waste liner, the maximum dose rates are strongly dependent on the specific contents. Additionally, as the package may be shipped as open or closed transport, the limiting dose rates are variable as well. As an example, maximum dose rates are calculated for the maximum allowable quantity of two individual isotopes. The two isotopes considered are Co-60 (γ), in Tables 5.1-2 (NCT) and Table 5.1-3 (HAC) and Cf-252 (n and γ) in Table 5.1-4 (NCT) and Table 5.1-5 (HAC). These results are calculated based on the isotopic unit dose rate values for a nonexclusive use shipment using the bare cask configuration, using the method outlined in Section 5.4.4.3.1. The resulting maximum activity in each example results in the limiting dose rate at 90% of the regulatory limit, based on the unit dose rate values and the regulatory limits at each location.

The maximum radiation levels for irradiated CANDU fuel waste, defined as irradiated CANDU fuel contents and irradiated hardware contents, are presented in Appendix 5.5.4.

Table 5.1-1 – Package Shielding Design Features

[redacted]

Table 5.1-2 – Co-60 NCT Dose Rates Example Calculation – Bare Cask

[redacted]

Table 5.1-3 – Co-60 HAC Dose Rates Example Calculation – Bare Cask

[redacted]

Table 5.1-4 – Cf-252 NCT Dose Rates Example Calculation – Bare Cask

[redacted]

Table 5.1-5 – Cf-252 HAC Dose Rates Example Calculation – Bare Cask

[redacted]

This page intentionally left blank.

5.2 Source Specification

The radioactive contents of the package are restricted to transuranic (TRU) waste and irradiated fuel waste (IFW), in the form of low enriched uranium (LEU) fuel waste and irradiated CANDU fuel and hardware. CANDU fuel and hardware waste contents, which are well defined, are evaluated separately in Section 5.5.4. However, the radionuclide inventories of the TRU waste and LEU contents are highly variable and dependent on the individual waste container or fuel waste liner. Thus, the neutron and gamma sources are dependent on the isotopic inventory of the contents. The isotopic inventory in each TRU waste or LEU content is characterized individually and is based on the waste materials in the specific contents. The neutron and gamma sources used for the dose rate analysis of the package are generic, so that the dose rates of specific contents can be determined based on the generic source terms analyzed.

Dose rates are calculated individually for gamma and neutron energy groups, so that with the calculated energy group dose rates and the isotopic inventory from a specific content, bounding dose rates can be calculated individually for each shipment. The individual dose rate calculations are for each energy group, G, based on the photon and neutron source spectra groups listed below in Table 5.2-1 and Table 5.2-2. The dose rate calculation for each energy group considers a monoenergetic source at the upper bound of the group (e.g. for the 0.1 - 0.2 MeV group, the source energy is 0.2 MeV).

Each TRU waste or LEU content is characterized as a specific isotopic inventory. For each isotope in the contents, a dose rate is determined based on the calculated energy group dose rates and a grouped source spectrum of the isotope, as calculated in the [redacted] version 6.2.2 [5.3]. With the dose rate contribution of each isotope calculated, compliance is verified by summing the contribution from all isotopes in the TRU waste LEU waste that is being transported.

The isotopic inventories of the characterized contents are considered current at the time of transport. Thus, there is no concern of an increase in source term over time during the transport.

5.2.1 Gamma Source

The gamma energy groups shown in Table 5.2-1 are based on a generic grouping structure developed for this package. The source of each isotope in the contents is determined based on 1 TBq of activity, using the [redacted] the gamma emissions into the energy groups shown in Table 5.2-1 for a defined gamma source from 1 TBq of the specific isotope, accounting for both gammas that are directly emitted and from Bremsstrahlung. Using the bounding calculated dose rates for each energy group, the dose rate contribution from each isotope is determined, and with the isotopic inventory of the contents, the total external dose

rates can be calculated. As an example, the [redacted] Cf-252 gamma source is shown in Table 5.2-1.

5.2.2 Neutron Source

The neutron energy groups shown in Table 5.2-2 are based on a generic grouping structure developed for this package. The source of each isotope in the contents is determined based on 1 TBq of activity, using the [redacted] the neutron emissions into the energy groups shown in Table 5.2-2 for a defined neutron source from 1 TBq of the specific isotope, accounting for neutrons from both spontaneous fission and α,n reactions. Using the bounding calculated dose rates for each energy group, the dose rate contribution from each isotope is determined, and with the isotopic inventory of the contents, the total external dose rates can be calculated. As an example, the [redacted] Cf-252 neutron source is shown in Table 5.2-2.

Table 5.2-1 – Photon Source Energy Group Structure

Group	Boundaries (MeV)		Cf-252 Spectrum (γ/s/TBq)
	Upper	Lower	
1	12	10	5.1622E+06
2	10	8.0	7.0522E+07
3	8.0	6.0	6.2384E+08
4	6.0	4.0	5.5186E+09
5	4.0	3.0	1.2284E+10
6	3.0	2.5	1.3410E+10
7	2.5	2.0	2.3126E+10
8	2.0	1.8	1.1711E+10
9	1.8	1.5	3.3486E+10
10	1.5	1.34	1.9557E+10
11	1.34	1.2	2.5322E+10
12	1.2	1.0	5.7284E+10
13	1.0	0.9	2.8643E+10
14	0.9	0.8	2.8643E+10
15	0.8	0.7	2.8543E+10
16	0.7	0.67	8.5338E+09
17	0.67	0.6	1.9912E+10
18	0.6	0.5	2.8446E+10
19	0.5	0.4	2.8446E+10
20	0.4	0.3	2.8446E+10
21	0.3	0.2	1.4223E+10
22	0.2	0.1	1.5337E+08

Table 5.2-2 – Neutron Source Energy Group Structure

Group	Boundaries (MeV)		Cf-252 Spectrum (n/s/TBq)
	Upper	Lower	
1	20.0	15.0	7.4565E+06
2	15.0	10.0	3.0643E+08
3	10.0	7.50	1.5154E+09
4	7.50	5.00	7.7705E+09
5	5.00	4.00	8.2522E+09
6	4.00	3.00	1.4200E+10
7	3.00	2.50	1.0169E+10
8	2.50	2.25	5.9830E+09
9	2.25	2.00	6.6084E+09
10	2.00	1.75	7.2311E+09
11	1.75	1.50	7.8208E+09
12	1.50	1.25	8.3330E+09
13	1.25	1.10	5.1897E+09
14	1.10	1.00	3.5122E+09
15	1.00	0.90	3.5341E+09
16	0.90	0.80	3.5341E+09
17	0.80	0.70	3.5070E+09
18	0.70	0.60	3.4470E+09
19	0.60	0.50	3.3451E+09
20	0.50	0.40	3.1895E+09
21	0.40	0.30	2.9622E+09
22	0.30	0.20	2.6329E+09
23	0.20	0.10	2.1375E+09
24	0.10	0.05	7.8503E+08

5.3 Shielding Model

The following subsections describe the [redacted] shielding model geometry and source configuration for all dose rate calculations of the package.

5.3.1 Configuration of Source and Shielding

5.3.1.1 [redacted] Shielding Model - Package Geometry

The [redacted] model package geometry for the dose rate calculations is based on the dimensions provided in the package licensing drawings. Additional features and attachments of the OSV are neglected (trunnions, tie-down arms, brackets, turnbuckles, etc.). All bolts and inserts in the CCV and OSV lids are modeled as the same material as the component (SS for the CCV and DCI for the OSV). The resultant localized reductions in the shielding effectiveness of the CCV and OSV are negligible. The foam and outer skin of the impact limiters are conservatively assumed to be void, neglecting any additional attenuation or scattering provided by the material. Only the [redacted] inner shells of the impact limiters are modeled. Credit is taken for the offset provided by the impact limiters for the NCT top and bottom surface dose rates, based on the maximum impact limiter deformation resulting from the NCT free drop, as discussed in Chapter 2.

Based on the packaging general arrangement drawings in Section 1.3.3, the thickness of the OSV body side wall, base, and lid are conservatively all reduced by 1/8-inch to account for casting tolerances. The CCV body and lid are composed of ASME plate and forging components, with much tighter tolerances. The permissible variation under the specified thickness for ASME plate material is 0.01 inches [5.2]. Thus, these small tolerances are neglected for in the [redacted] geometry.

The package MCNP model geometry is shown in Figure 5.3-1, including all significant axial and radial shield thickness dimensions, with dimensions listed in Table 5.3-1. For the side 1-meter HAC model, a 6-inch diameter by ¼-inch deep depression is modeled on the outer side of the OSV side wall. This bounds the maximum damage to the OSV resulting from the HAC puncture test, as discussed in Chapter 2. This location of the puncture damage is shown in black on the right side of the OSV in Figure 5.3-1 and is only included in the HAC model. Otherwise, the package geometry for the HAC and NCT shielding models are identical. As discussed in Chapter 2, the impact limiters will remain attached to the OSV based on the sequence of HAC tests. Thus, for the HAC model the ILS[redacted] inner shells are modeled, but the 1-meter dose

rate is conservatively measured from the surface of the ILS inner shell, taking no credit for the impact limiter foam and outer shells.

5.3.1.2 [redacted] Shielding Model - Source Geometry

The contents for the package are limited to TRU or irradiated fuel waste. [redacted]

5.3.1.3 [redacted] Shielding Model – Tally Locations

The [redacted] dose rate calculations utilize cell tallies that determine the particle flux at the location of interest. The cell tallies are small void volumes, such that they do not affect the transport of particles in [redacted] and the flux is not averaged over too large of an area. The cell tallies are approximately 100 cm^3 (i.e. 10 cm wide x 10 cm tall x 1 cm thick). The side package surface tally is formed with an arc with a 10° inner angle.

The distances for the [redacted] tallies used to calculate external dose rates and establish compliance with all regulatory dose rates are provided in Table 5.3-2. Note that in this table, all listed dimensions are from the center of the CCV cavity. Tally locations are conservatively based on an 8-foot trailer width.

As the source is concentrated into a single point, and there are no concerns of radiation streaming through the shield material, the maximum dose point is defined at the location directly out the side, top, or bottom of the package from the source. Thus, only a single tally is used for each dose rate location. Due to the concentrated point source and uniform nature of the shielding geometry, the maximum dose rates are from straight penetration through the package shielding, and the tally used for each dose rate location is at the position of the highest dose rate. The top and bottom dose rate locations of the NCT and HAC tallies are shown in Figure 5.3-4, and the side dose rate locations of the NCT and HAC tallies are shown in Figure 5.3-5. The axial or radial distance of each of the tallies shown in these figures, from the center of the package, is listed in Table 5.3-2. Although the impact limiters are not explicitly modeled, the spacing provided for the top and bottom package surface dose rates is considered. [redacted]

[redacted]

5.3.2 Material Properties

The only materials defined for the [redacted] shielding models are DCI and [redacted]. The compositions and densities of these materials are summarized in Table 5.3-3 and the [redacted] neutron and photon input cards are shown in Table 5.3-4.

Table 5.3-1 – Primary [redacted] Model Package Dimensions

[redacted]

Table 5.3-2 – Shielding Model – Tally Locations

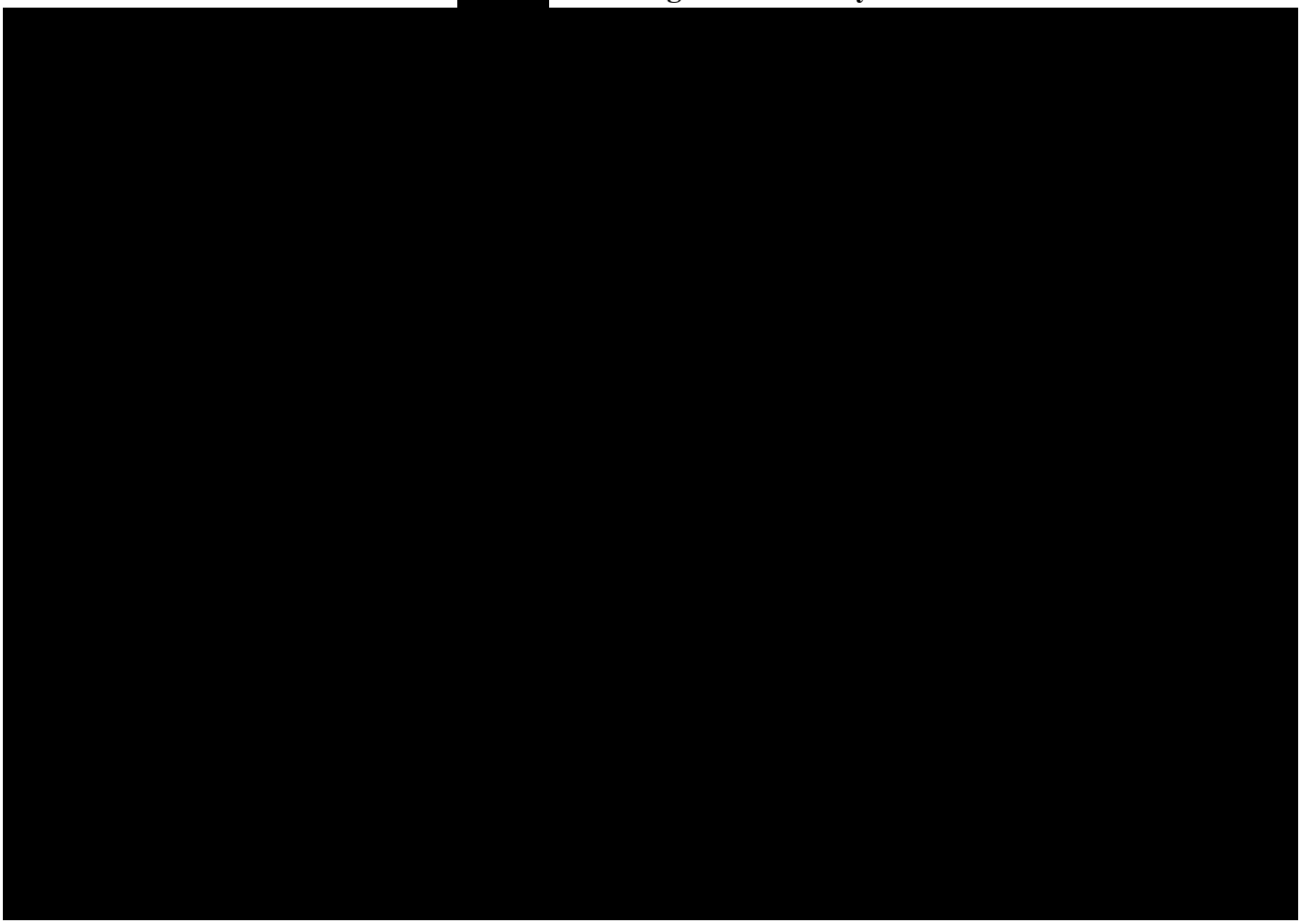


Table 5.3-3 – Material Compositions

[redacted] (8.00 g/cm^3)		DCI (7.1 g/cm^3)	
Element	**Composition (wt%)**	**Element**	**Composition (wt%)**
C	4.0000E-04	C	7.45900E-03
Si	5.0000E-03	Si	9.12000E-03
P	2.3000E-04	Mg	3.16000E-04
S	1.5000E-04	P	1.72000E-04
Cr	1.9000E-01	Cr	6.75000E-04
Mn	1.0000E-02	Mn	2.54900E-03
Fe	7.0173E-01	Fe	9.67639E-01
Ni	9.2500E-02	Ni	1.08910E-02
		Cu	1.17900E-03

Table 5.3-4 – [redacted] Material Definitions

Photon Input			
[redacted] (8.00 g/cm^3)		DCI (7.1 g/cm^3)	
6000.84p	-4.0000E-04	6000.84p	-7.45900E-03
14000.84p	-5.0000E-03	14000.84p	-9.12000E-03
15000.84p	-2.3000E-04	12000.84p	-3.16000E-04
16000.84p	-1.5000E-04	15000.84p	-1.72000E-04
24000.84p	-1.9000E-01	16000.84p	-6.75000E-04
25000.84p	-1.0000E-02	25000.84p	-2.54900E-03
26000.84p	-7.0173E-01	26000.84p	-9.67639E-01
28000.84p	-9.2500E-02	28000.84p	-1.08910E-02
		29000.84p	-1.17900E-03
Neutron Input			
[redacted] (8.00 g/cm^3)		DCI (7.1 g/cm^3)	
6000.80c	-4.0000E-04	6000.80c	-7.4593E-03
14028.80c	-4.5933E-03	14028.80c	-8.3782E-03
14029.80c	-2.4168E-04	14029.80c	-4.4083E-04
14030.80c	-1.6499E-04	14030.80c	-3.0095E-04
15031.80c	-2.3000E-04	12024.80c	-2.4608E-03
16032.80c	-1.4207E-04	12025.80c	-3.2454E-04
16033.80c	-1.1568E-06	12026.80c	-3.7157E-04
16034.80c	-6.7534E-06	15031.80c	-1.7242E-04
16036.80c	-1.6825E-08	24050.80c	-2.8188E-05
24050.80c	-7.9300E-03	24052.80c	-5.6528E-04
24052.80c	-1.5903E-01	24053.80c	-6.5333E-05
24053.80c	-1.8380E-02	24054.80c	-1.6569E-05
24054.80c	-4.6614E-03	25055.80c	-2.5485E-03
25055.80c	-1.0000E-02	26054.80c	-5.4629E-02
26054.80c	-3.9617E-02	26056.80c	-8.8927E-01
26056.80c	-6.4490E-01	26057.80c	-2.0905E-02
26057.80c	-1.5160E-02	26058.80c	-2.8308E-03
26058.80c	-2.0529E-03	28058.80c	-7.3184E-03
28058.80c	-6.2158E-02	28060.80c	-2.9161E-03
28060.80c	-2.4768E-02	28061.80c	-1.2888E-04
28061.80c	-1.0946E-03	28062.80c	-4.1765E-04
28062.80c	-3.5472E-03	28064.80c	-1.0980E-04
28064.80c	-9.3254E-04	29063.80c	-8.0746E-04
		29065.80c	-3.7167E-04

Figure 5.3-1 – [redacted] Shielding Model – Package Geometry

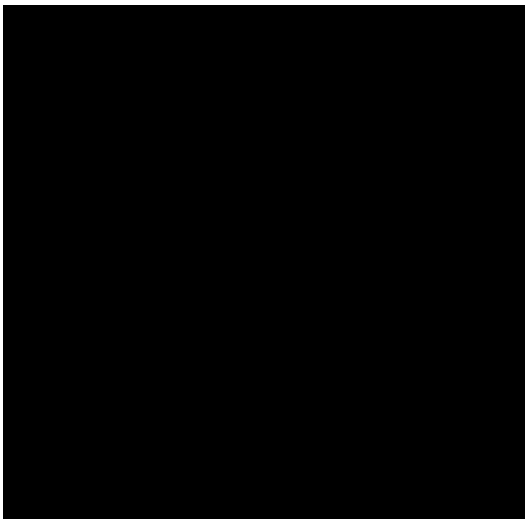


Figure 5.3-2 – [redacted] Shielding Model – NCT Source Configuration

Figure 5.3-3 – [redacted] Shielding Model – HAC Source Configurations

Figure 5.3-4 – [redacted] Shielding Model – Axial Tally Locations

Figure 5.3-5 – [redacted] Shielding Model – Side Tally Locations

5.4 Shielding Evaluation

5.4.1 Methods

For this dose rate analysis, the [redacted] particle transport code is used to calculate external dose rates for the package and to demonstrate compliance with the regulatory dose rate limits in 10 CFR 71.

Multiple assumptions and approaches are used in the dose rate analysis to ensure bounding dose rate calculations. The most significant approaches/assumptions are:

1. All dose rate limits are reduced by 10%. This provides direct margin to the set activity limits.

2. [redacted]

3. [redacted]. The radioactive source material for both TRU waste and natural irradiated fuel waste is generally distributed throughout attenuating media in the waste. Additionally, both waste types are contained in a metal drum and/or liner which is secured in the cavity with additional shoring to provide structural stability for the contents.

4. [redacted]

5. The energy grouping of the source spectra is evaluated by rounding up of all photon and neutron energies to the upper bound of each group. While the effect of rounding up of energies is strongly dependent on the spectrum of each isotope individually, it will always result in overestimated dose rates.

Additionally, NCT dose rates are measured prior to shipment. Pre-shipment dose rate measurements are not relied upon as a means for demonstrating compliance with dose rate limits. However, these measurements are conducted prior to every shipment to provide assurance that the external dose rates are below the regulatory limits. Thus, the pre-shipment dose rate

measurements are a helpful tool and support that the calculated dose rates in the shielding analysis are conservative and bounding.

5.4.1.1 Computer Codes –

5.4.1.2

5.4.1.3 Dose Rate Calculations

Dose rates are calculated in as described below. The dose rate, normalized per emitted particle, is calculated in by tallying the particle flux at each dose rate location and applying flux-to-dose rate conversion factors (see Table 5.4-5):

$$D_{X,G,p} = \phi_{X,E,p} \cdot DF_{p,E} \qquad \text{[EQN. 1]}$$

Where,

$D_{X,G,p}$ = output dose rate at location X, for particle type p from group G

$\phi_{X,E,p}$ = calculated flux at location X, for particle type p tallied at energy E

$DF_{p,E}$ = flux-to-dose rate conversion factor for particle type p at energy E

To account for the uncertainty in the result of the statistical [redacted] calculation, the calculated dose rate is increased by 2σ:

$$D^{\sigma}_{X,G,p} = D_{X,G,p} + 2 \cdot D_{X,G,p} \cdot \sigma_{X,G,p} \quad \text{[EQN. 2]}$$

Where,

$D^{\sigma}_{X,G,p}$ = Dose rate at location X, for particle type p from group G including uncertainty

$D_{X,G,p}$ = [redacted] output dose rate at location X, for particle type p from group G

$\sigma_{X,G,p}$ = Fractional standard deviation at location X, for particle type p from group G

Using the [redacted] calculated dose rates and the neutron and gamma source spectra of an isotope, a unit dose rate of each isotope can be calculated for each location:

$$DR_{X,i} = \sum_{G=1}^{m} D^{\sigma}_{X,G,n} \cdot E_{i,G,n} + \sum_{G=1}^{m} D^{\sigma}_{X,G,\gamma} \cdot E_{i,G,\gamma} \quad \text{[EQN. 3]}$$

Where,

$DR_{X,i}$ = Dose rate at location X from 1 TBq of isotope i

$D^{\sigma}_{X,G,n}$ = Dose rate at location X, for neutrons from group G including uncertainty

$D^{\sigma}_{X,G,\gamma}$ = Dose rate at location X, for gammas from group G including uncertainty

$E_{i,G,n}$ = Emitted neutrons per second in energy group G, from 1 TBq of isotope i

$E_{i,G,\gamma}$ = Emitted gammas per second in energy group G, from 1 TBq of isotope i

m = Number of neutron/gamma energy groups

With the unit dose rate calculated for each isotope, the resulting dose rate from a given load of isotopes can be calculated at each regulatory location:

$$DR_X = \sum_{i=1}^{I} DR_{X,i} \cdot A_i \quad \text{[EQN. 4]}$$

Where,

DR_X = Total dose rate at regulatory location X

$DR_{X,i}$ = Dose rate at location X from 1 TBq of isotope i

A_i = Activity of isotope i, in TBq

I = Number of isotopes

Alternatively, instead of explicitly calculating dose rates, compliance with regulatory dose rate limits can be demonstrated through individual isotope activity limits and the sum of fractions method. For this method, the activity limit for each isotope is calculated based on the regulatory dose rate limit and the unit dose rate for the dose rate location. The activity limit is set based on the minimum value calculated across all regulatory dose rate locations:

$$A_{Limit,i} = \text{Min}\left(\frac{DR_{X,Limit}}{DR_{X,i}}\right) \quad \text{[EQN. 5]}$$

Where,

$A_{Limit,i}$ = Activity limit of isotope i, in TBq

$DR_{X,Limit}$ = 90% of regulatory dose rate limit at location X (e.g., 0.09 mSv/hr for 2m)

$DR_{X,i}$ = Dose rate at location X from 1 TBq of isotope i

Compliance with dose rates is demonstrated through the sum of fractions method using the activity limit and known activity for each isotope in the contents. If the sum of the fractions is less than 1, external dose rates will be less than the regulatory limits:

$$\sum_{i=1}^{I} \frac{A_i}{A_{Limit,i}} \leq 1 \quad \text{[EQN. 6]}$$

Where,

A_i = Activity of isotope i, in TBq

$A_{Limit,i}$ = Activity limit of isotope i, in TBq

I = Number of isotopes

5.4.2 Input and Output Data

Input data for source terms and geometry/materials are summarized in Sections 5.2 and 5.3, respectively. A sample [redacted] input file for 1.0 MeV neutron emission under NCT with side detectors is shown in Figure 5.4-1.

The tally fluctuation chart and probability density function plot were studied for each [redacted] tally to ensure proper tally bin convergence. This, along with a check of the reported fractional standard deviation (σ) for each tally bin and the additional statistical information reported for MCNP tallies, ensures the reliability of all [redacted] calculated dose rate results.

5.4.3 Flux-to-Dose Rate Conversion

Consistent with guidance of Section 5.5.4.3 of NUREG-1617 [5.6], the ANSI/ANS-6.1.1 1977 [5.7] gamma and neutron flux-to-dose rate conversion factors are used. The specific values are listed in Table 5.4-5.

5.4.4 External Radiation Levels

5.4.4.1 NCT Radiation Levels

Table 5.4-2 and Table 5.4-3 list the calculated NCT dose rates for each energy group for photons and neutrons, respectively. The results in these tables are based directly on the results from [redacted] and include the 2σ uncertainty. Thus, the units are in *(mSv/hr)*(s/emitted particle)*, where the emitted particle is either neutrons or gammas (see EQN 1 in Section 5.4.1.3). When these values are multiplied by the source spectrum of a given isotope, which has units of *(emitted particle/s)/TBq*, the resulting value is a unit dose rate, in (*mrem/hr)/TBq*. All tallies are at the location of the maximum dose rate (see discussion in Section 5.3.1.3).

5.4.4.2 HAC Radiation Levels

Table 5.4-4 and Table 5.4-5 list the calculated HAC dose rates for each energy group for a point source on the CCV wall of photons and neutrons, respectively. The results in these tables are based directly on the results from [redacted] and include the 2σ uncertainty added on. Thus, the units are in *(mSv/hr)*(s/emitted particle)*, where the emitted particle is either neutrons or gammas (see EQN 1 in Section 5.4.1.3). So, when these values are multiplied by the source spectrum of a given isotope, which has units of *(emitted particle/s)/TBq*, the resulting value is a unit dose rate, in (*mSv/hr)/TBq*. All tallies are at the location of the maximum dose rate (see discussion in Section 5.3.1.3).

5.4.4.3 Demonstrating Compliance with 10 CFR 71 Dose Rate Requirements

As [redacted] calculates dose rates for energy groups for individual gamma and neutron energies, additional calculations are required to demonstrate compliance with the 10 CFR 71 dose rate requirements. Any contents that are to be transported in the package must be characterized, such that there is a determined activity, in TBq, of each isotope present. Using calculated unit dose rate values for each isotope, and the isotope list for the specific contents, the external dose rates for the specific contents can be calculated.

5.4.4.3.1 Calculating Isotope Dose Rate/Ci Values

To calculate the contribution to external dose rates from an individual isotope, a unit dose rate value is calculated for each isotope at each dose rate location. To do this, the [redacted] code package is used to determine grouped neutron and gamma energy spectra from 1 TBq of the isotope of interest. This code can be used to group the neutron and gamma spectra into the group structures shown in Table 5.2-1 and Table 5.2-2. By default, the grouped energy spectra for the isotope output by the [redacted] account for secondary particles (Bremsstrahlung and α,n) based on interactions in a UO_2 matrix. As an example, the grouped spectrum for 1 TBq of Cf-252 from the [redacted] is shown in Table 5.4-6. Using the grouped source spectrum from 1 TBq of the isotope, the unit dose rate of the isotope at a dose rate location can be calculated by multiplying the emissions in each energy group by the respective dose rate per emitted particle at the dose rate location of interest (see EQN 3 in Section 5.4.1.3). As an example, the 2-meter unit dose rate calculation of Cf-252 is shown in Table 5.4-7. By summing the total 2-meter neutron and photon dose rates calculated in this table, the total unit dose rate of Cf-252 is calculated for the 2-meter dose rate location (i.e.. 0.24 + 308.23 = 308.47 mSv/hr/TBq).

The unit dose rates for most isotopes are provided in Table 7.5-1 (exclusive use) and Table 7.5-2 (nonexclusive use) when using the bare cask. If a [redacted] SIA is utilized, the unit dose rates are taken from Table 7.5-3 (exclusive use) or Table 7.5-4 (nonexclusive use), Table 7.5-5 (exclusive use) or Table 7.5-6 (nonexclusive use), or Table 7.5-7 (exclusive use) or Table 7.5-8 (nonexclusive use), respectively. Note that the unit dose rate for additional isotopes not on the list may be determined and used for dose rate calculations using the method above.

5.4.4.3.2 Compliance Method 1 – Total Dose Rate Calculation Method

The total dose rate contribution from each isotope in the contents at each regulatory dose rate location is calculated by multiplying the unit dose rate value, as determined in Section 5.4.4.3.1,

by the activity of the respective isotope in the contents. The dose rate contributions per regulatory dose rate location are summed from all isotopes in the contents, to determine the total dose rate at each regulatory location (see EQN 4 in Section 5.4.1.3). If the calculated total dose rate is less than 90% of the regulatory limit, the external dose rates of the package comply with the regulatory limits, and the contents are acceptable for shipment. For example, for 0.001 TBq of Cf-252 at the 1-meter dose rate location, this calculation would be:

$$308.47\frac{\text{mSv/hr}}{\text{TBq}}\cdot 0.001\ \text{TBq} = 0.031\ \text{mSv/hr} < 0.09\ \text{mSv/hr}\ (\textit{1-meter limit})$$

Thus, 0.001 TBq of Cf-252 does not result in a dose rate greater than the 1-meter regulatory limit. This calculation is repeated for each regulatory location to calculate the dose rate at each location and demonstrate that no external dose rate exceeds its respective regulatory limit.

5.4.4.3.3 Compliance Method 2 – Sum of Fractions Method

The activity limit of each isotope in the contents at each regulatory dose rate location is calculated by dividing 90% of the dose rate limit at each location (e.g., 0.09 mSv/hr [9 mrem/hr] at 2 meters) by the calculated unit dose rate value. The overall activity limit of each isotope is set as the minimum value based on all regulatory dose rate locations (See EQN 5 in Section 5.4.1.3). The activity limit values for most isotopes are provided in Table 7.5-1 (exclusive use) or Table 7.5-2 (nonexclusive use) when using the bare cask. If a [redacted] inch SIA is utilized, the unit dose rate values are taken from Table 7.5-3 (exclusive use) or Table 7.5-4 (nonexclusive use), Table 7.5-5 (exclusive use) or Table 7.5-6 (nonexclusive use), or Table 7.5-7 (exclusive use) or Table 7.5-8 (nonexclusive use), respectively. Note that the activity limits for additional isotopes not on this list may be determined and used for the sum of fractions method using the method above. The activity limit fraction of each isotope is then calculated by dividing the activity of the isotope in the contents by the calculated activity limit. If the sum of the activity limit fractions from all isotopes in the contents is less than or equal to 1, the external dose rates of the package comply with the regulatory limits, and the contents are acceptable for shipment (see EQN 6 in Section 5.4.1.3).

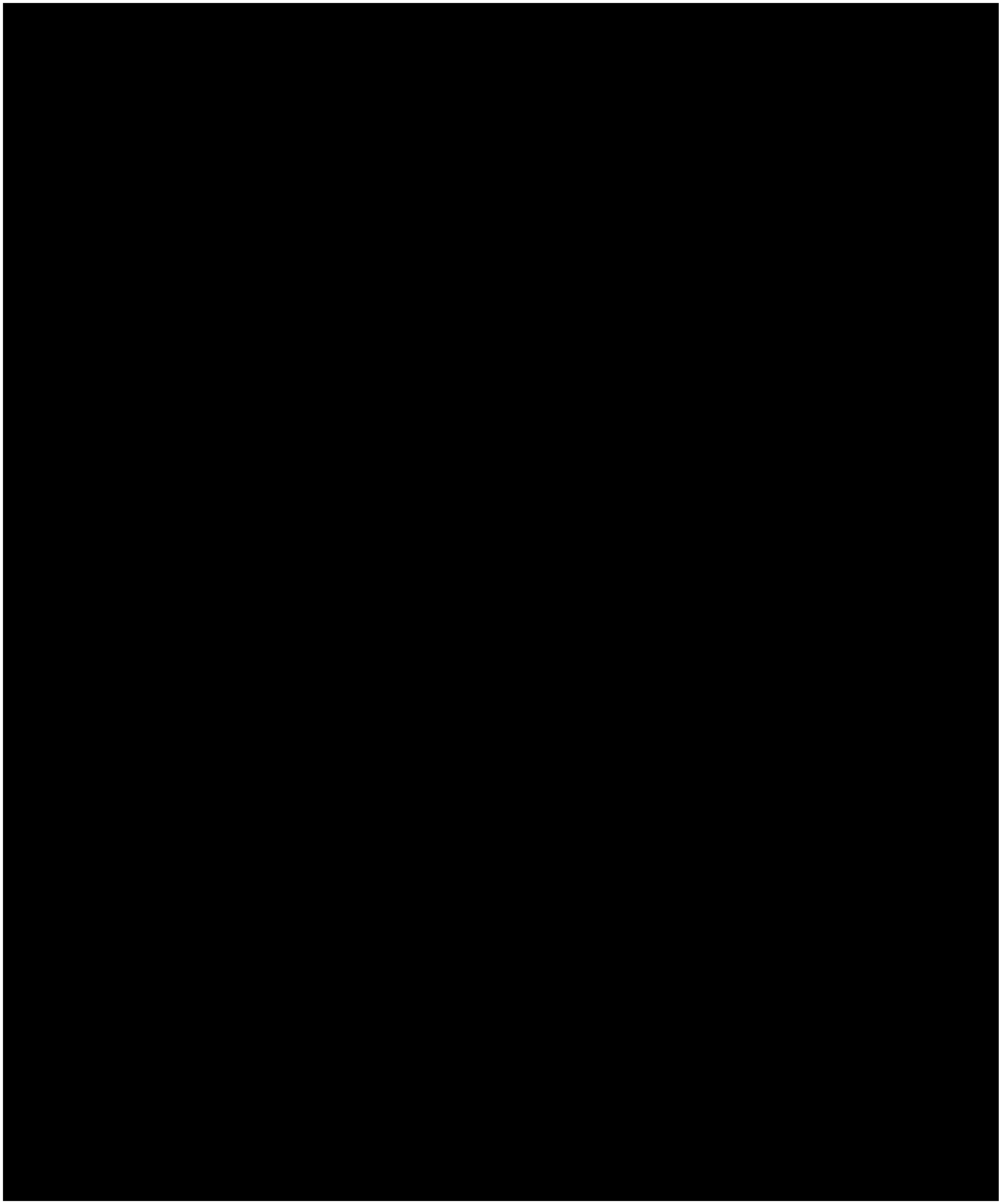
For example, with the total combined photon and neutron 1-meter unit dose rate value of 308.47 mSv/hr/TBq for Cf-252, and this location being the limiting dose rate location, the activity limit for Cf-252 is 2.92E-04 TBq. For a calculated 1-meter unit dose rate value of 0.4788 mSv/hr/TBq for Co-60, and this location being the limiting dose rate location, the activity limit for Co-60 is 0.188 TBq. With these activity limits for both of these isotopes, compliance for a container with a given activity of these two isotopes can be demonstrated via the sum of fractions

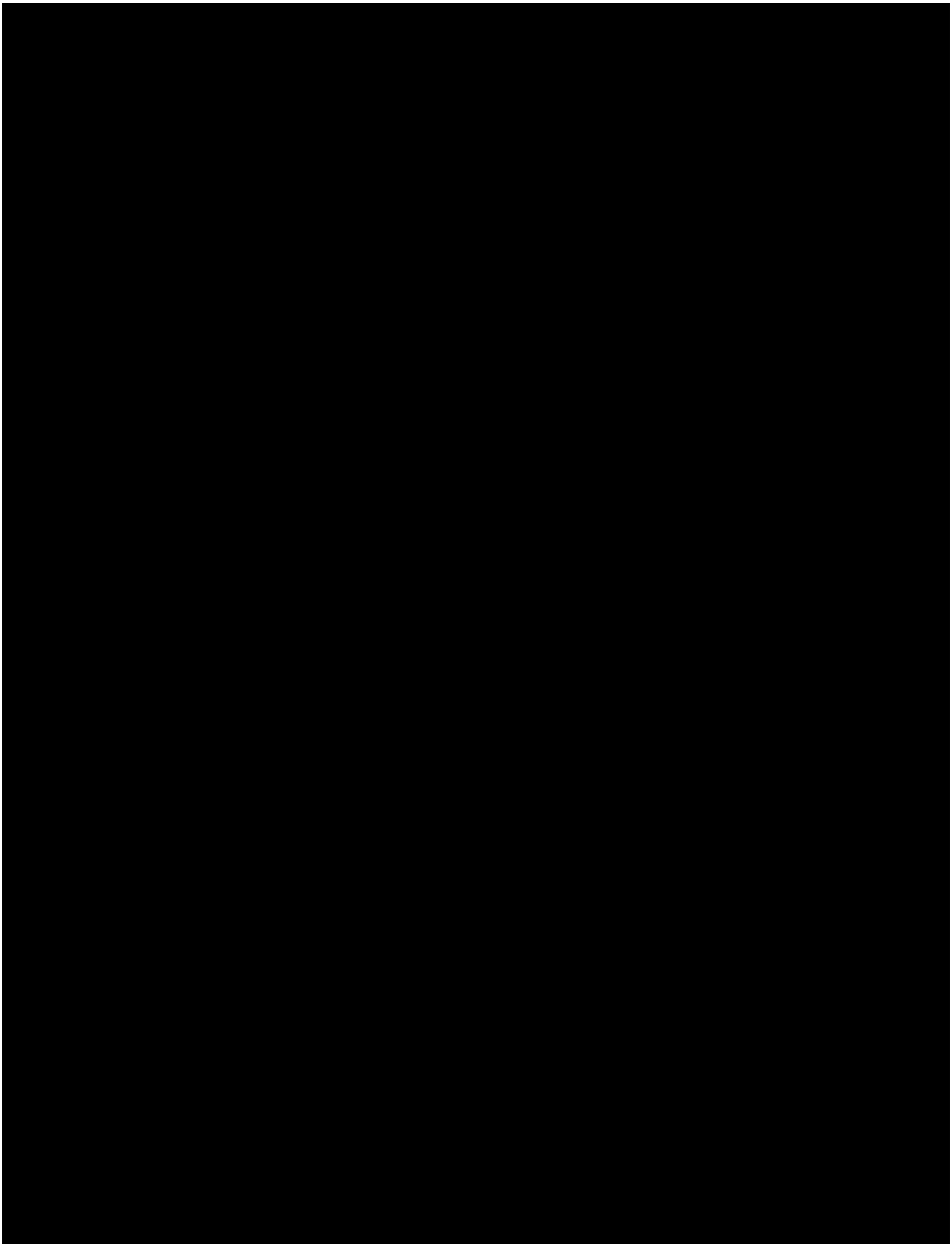
method. For example, for contents containing 0.002 TBq of Cf-252 and 0.059 TBq of Co-60, the sum of fractions calculation would be:

$$\frac{0.002\ \text{TBq}}{0.00292\ \text{TBq}} + \frac{0.059\ \text{TBq}}{0.188\ \text{TBq}} = 0.685 + 0.314 = 0.999 < 1.0$$

Because the sum of fractions does not exceed 1, the resulting external dose rates for a container with these quantities of Cf-252 and Co-60 would not exceed any of the regulatory dose rate limits, and it would be acceptable to ship in the package. Note, that if any value is rounded, it should always be rounded up to ensure that the actual sum never exceeds 1 due to rounding.

Figure 5.4-1 – [redacted]





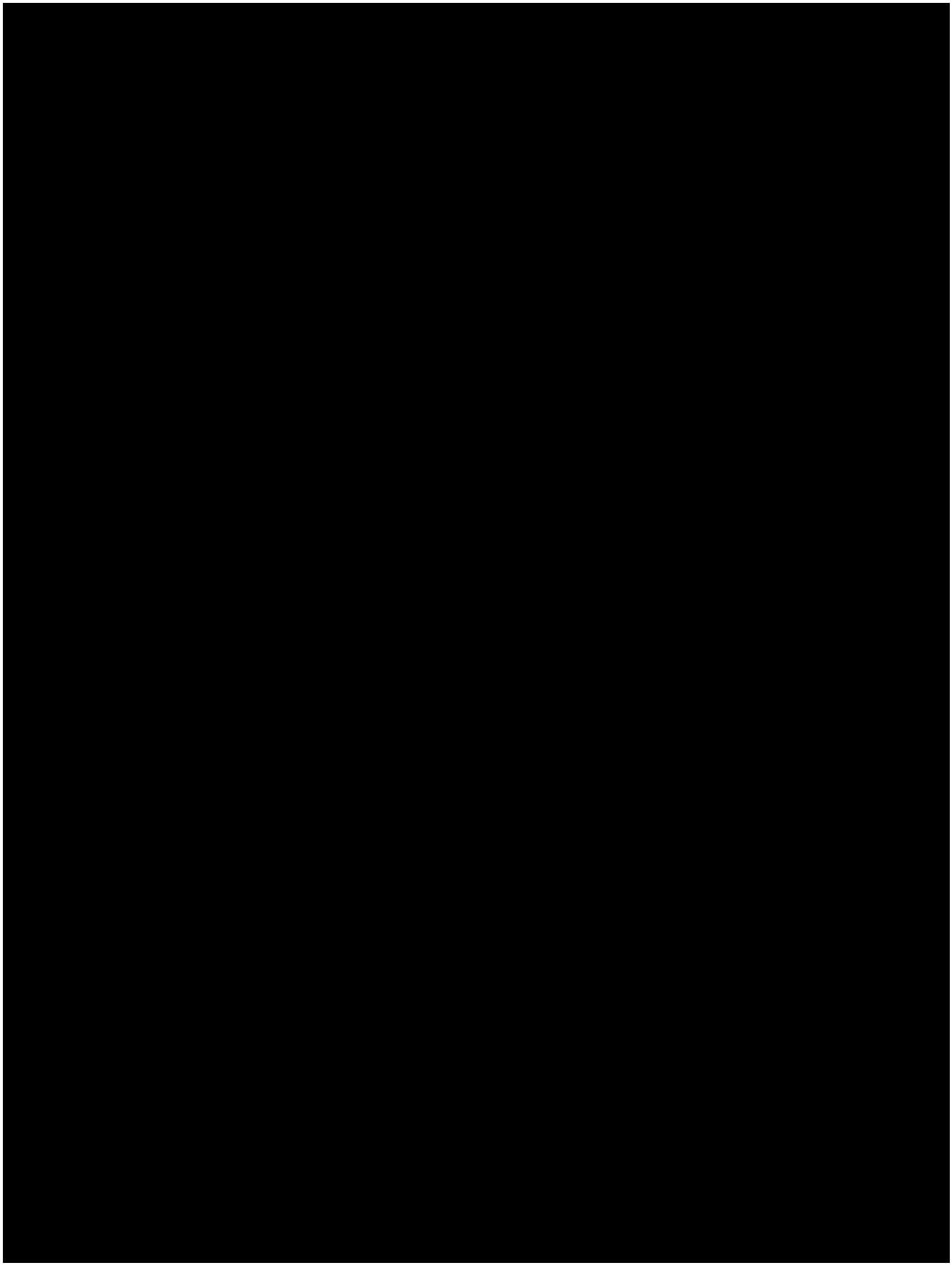


Table 5.4-1 – ANSI/ANS-6.1.1 1977 Flux-to-Dose Conversion Factors

Gamma Conversion Factors		Neutron Conversion Factors	
Gamma Energy (MeV)	Conversion Factor (mrem/hr)/(γ/cm^2-s)	Neutron Energy (MeV)	Conversion Factor (mrem/hr)/(n/cm^2-s)
0.01	3.96E-03	2.50E-08	3.67E-03
0.03	5.82E-04	1.00E-07	3.67E-03
0.05	2.90E-04	1.00E-06	4.46E-03
0.07	2.58E-04	1.00E-05	4.54E-03
0.10	2.83E-04	1.00E-04	4.18E-03
0.15	3.79E-04	1.00E-03	3.76E-03
0.20	5.01E-04	1.00E-02	3.56E-03
0.25	6.31E-04	1.00E-01	2.17E-02
0.30	7.59E-04	5.00E-01	9.26E-02
0.35	8.78E-04	1.00E+00	1.32E-01
0.40	9.85E-04	2.50E+00	1.25E-01
0.45	1.08E-03	5.00E+00	1.56E-01
0.50	1.17E-03	7.00E+00	1.47E-01
0.55	1.27E-03	1.00E+01	1.47E-01
0.60	1.36E-03	1.40E+01	2.08E-01
0.65	1.44E-03	2.00E+01	2.27E-01
0.70	1.52E-03	---	---
0.80	1.68E-03	---	---
1.00	1.98E-03	---	---
1.40	2.51E-03	---	---
1.80	2.99E-03	---	---
2.20	3.42E-03	---	---
2.60	3.82E-03	---	---
2.80	4.01E-03	---	---
3.25	4.41E-03	---	---
3.75	4.83E-03	---	---
4.25	5.23E-03	---	---
4.75	5.60E-03	---	---
5.00	5.80E-03	---	---
5.25	6.01E-03	---	---
5.75	6.37E-03	---	---
6.25	6.74E-03	---	---
6.75	7.11E-03	---	---
7.50	7.66E-03	---	---
9.00	8.77E-03	---	---
11.0	1.03E-02	---	---
13.0	1.18E-02	---	---
15.0	1.33E-02	---	---

Table 5.4-2 – [redacted] NCT Gamma Dose Rate Summary

[redacted]

Table 5.4-3 – [redacted] NCT Neutron Dose Rate Summary

[redacted]

Table 5.4-4 – [redacted] HAC Gamma Dose Rate Summary

[redacted]

Table 5.4-5 – [redacted] HAC Neutron Dose Rate Summary

[redacted]

Table 5.4-6 – [redacted] Cf-252 Spectra

[redacted]

Table 5.4-7 – Cf-252 2-meter Unit Dose Rate Calculation

This page intentionally left blank.

5.5 Appendices

5.5.1 References

[5.1] U.S. Department of Energy, “Characteristics of Potential Repository Wastes,” DOE/RW-0184, Rev.1, 1992.

[5.2] American Society of Mechanical Engineers, "Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip," ASME SA-480/SA-480M, 2010 Edition with 2011 Addenda.

[5.3] [redacted]

[5.4] [redacted]

[5.5] Los Alamos National Laboratory, "Listing of Available ACE Data Tables," LA-UR-13-21822 Rev. 4, 2014.

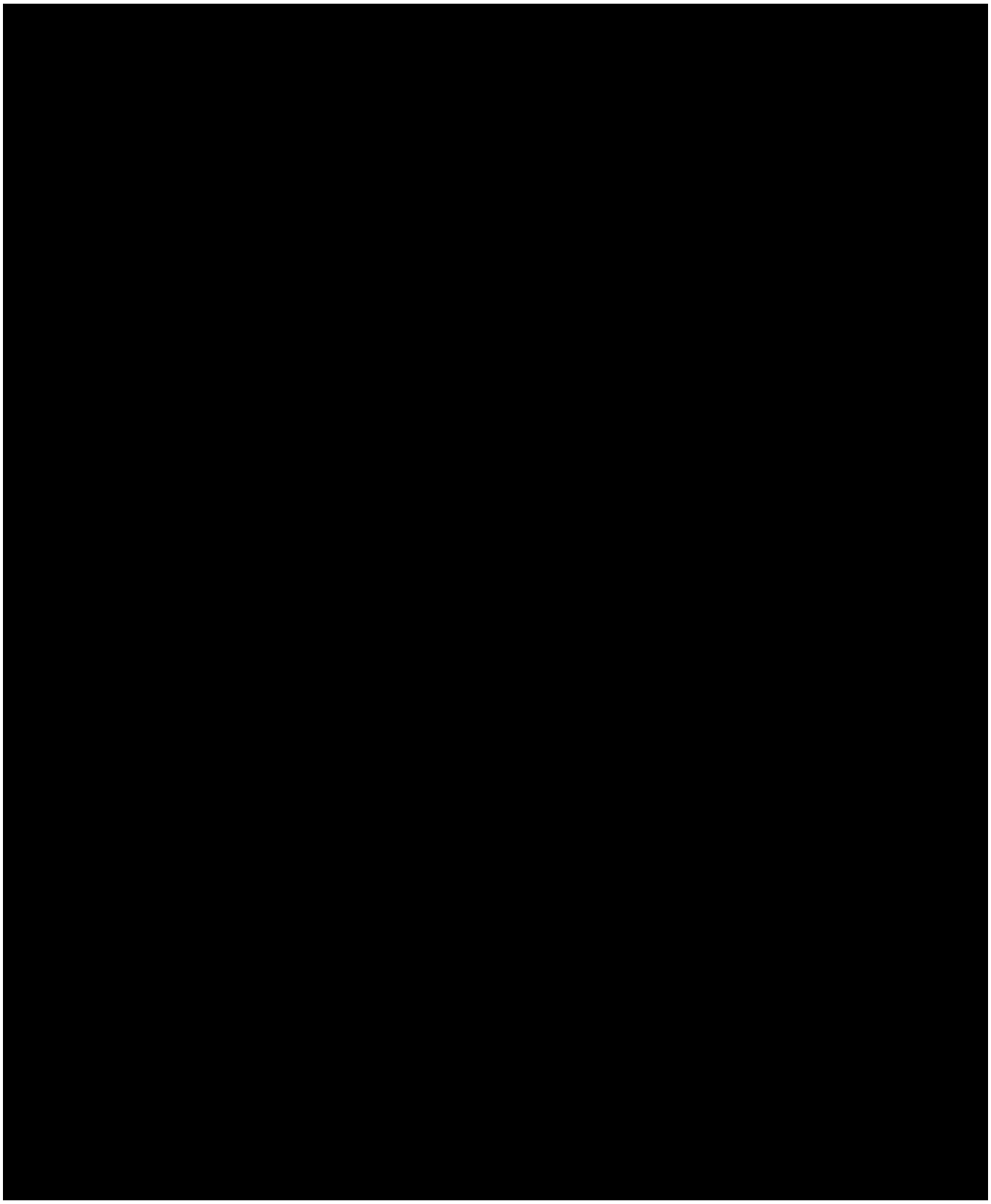
[5.6] U.S. Nuclear Regulatory Commission, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel," NUREG-1617, 2000.

[5.7] American Nuclear Society, "Neutron and Gamma Flux-To-Dose Conversion Factors," ANSI/ANS 6.1.1-1977, 1977.

[5.8] U.S. Department of Energy, "Annual Transuranic Waste Inventory Report," DOE/TRU-16-3425, Rev. 0, 2016.

[5.9] Pacific Northwest National Laboratory, "Compendium of Material Composition Data for Radiation Transport Modeling," PNNL-15780, Rev.1, 2011.

5.5.2 OSV Allowable Manufacturing Under Thickness



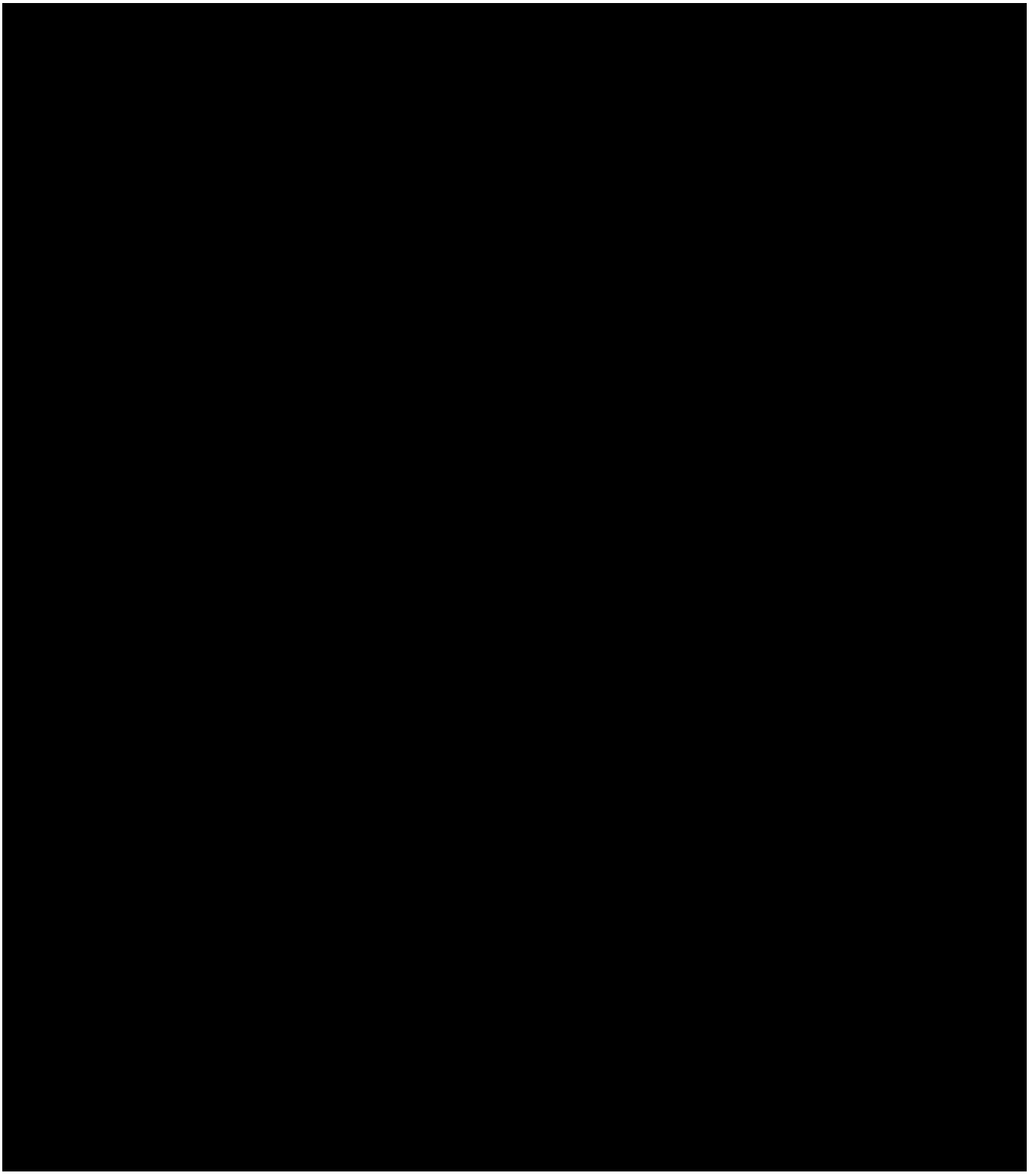


Table 5.5-1 – OSV Under Thickness Dose Rate Results

Figure 5.5-1 – OSV Under Thickness Model Changes – All Neutron Cases and Side Photon Cases

Figure 5.5-2 – OSV Under Thickness Model Changes – Top and Bottom Photon Cases

5.5.3 SIA Shielding Analysis

The purpose of this appendix is to determine dose rates and activity limits for the OPTIMUS®-H package when utilizing the [redacted]h Shield Insert Assembly (SIA). Views showing the [redacted] geometry analyzed for each are shown in Figure 5.5-3, Figure 5.5-4 and Figure 5.5-5. The minimum carbon steel wall thicknesses in each direction for each design is set based on the plate thicknesses of the components in the licensing drawings, as listed in Table 5.5-2 and shown in the respective figures. [redacted]

[redacted]

The results from the NCT [redacted] calculations for the [redacted] SIA are presented in Tables 5.5-3 and 5.5-4, and the isotopic unit dose rate and activity limit values for most isotopes are provided in Table 7.5-3 (exclusive use) and Table 7.5-4 (nonexclusive use). The results from the NCT [redacted] rate and activity limit values for most isotopes are provided in Table 7.5-5 (exclusive use) and Table 7.5-6 (nonexclusive use). The results from the NCT and HAC [redacted] calculations for the [redacted] SIA are presented in Tables 5.5-11 through 5.5-14, and the isotopic unit dose rate and activity limit values for most isotopes are provided in Table 7.5-7 (exclusive use) and Table 7.5-8 (nonexclusive use). The values in these tables are used to demonstrate compliance with external dose rates, as outlined in Section 5.4.4.3.

Table 5.5-2 – SIA Design Directional Thicknesses

Table 5.5-3 – [redacted] NCT Gamma Dose Rate Summary

Energy (MeV)	Dose Rates [(mSv/hr)*(s/emitted γ)]						
	Package Surface			Vehicle Surface	1-Meter	2-Meter	Driver Cab
	Top	Bottom	Side	Side	Side[(1)]	Side	
12.00	4.160E-11	1.736E-11	5.035E-11	1.287E-11	6.905E-12	1.922E-12	5.731E-13
10.00	3.703E-11	1.551E-11	4.426E-11	1.089E-11	6.056E-12	1.568E-12	4.461E-13
8.00	3.197E-11	1.344E-11	3.834E-11	9.411E-12	5.322E-12	1.359E-12	3.981E-13
6.00	2.557E-11	1.071E-11	3.049E-11	7.423E-12	4.185E-12	1.071E-12	3.076E-13
4.00	1.624E-11	6.609E-12	1.860E-11	4.438E-12	2.468E-12	6.201E-13	1.752E-13
3.00	1.025E-11	4.009E-12	1.110E-11	2.624E-12	1.433E-12	3.597E-13	1.024E-13
2.50	7.068E-12	2.691E-12	7.289E-12	1.694E-12	9.280E-13	2.356E-13	6.501E-14
2.00	4.141E-12	1.499E-12	3.977E-12	9.125E-13	4.972E-13	1.211E-13	3.556E-14
1.80	3.108E-12	1.099E-12	2.890E-12	6.503E-13	3.545E-13	8.963E-14	2.575E-14
1.50	1.790E-12	5.992E-13	1.529E-12	3.425E-13	1.837E-13	4.478E-14	1.241E-14
1.34	1.219E-12	3.939E-13	9.951E-13	2.183E-13	1.174E-13	2.932E-14	8.556E-15
1.20	8.234E-13	2.561E-13	6.318E-13	1.365E-13	7.382E-14	1.818E-14	5.022E-15
1.00	4.071E-13	1.187E-13	2.826E-13	6.023E-14	3.222E-14	7.460E-15	2.133E-15
0.90	2.643E-13	7.399E-14	1.725E-13	3.656E-14	1.954E-14	4.554E-15	1.296E-15
0.80	1.591E-13	4.228E-14	9.623E-14	2.025E-14	1.070E-14	2.587E-15	7.259E-16
0.70	8.673E-14	2.176E-14	4.795E-14	9.940E-15	5.267E-15	1.236E-15	3.471E-16
0.67	7.013E-14	1.736E-14	3.793E-14	7.821E-15	4.113E-15	9.604E-16	2.755E-16
0.60	4.035E-14	9.461E-15	2.008E-14	4.088E-15	2.179E-15	5.076E-16	1.448E-16
0.50	1.484E-14	3.185E-15	6.420E-15	1.298E-15	6.784E-16	1.547E-16	4.381E-17
0.40	3.605E-15	6.798E-16	1.277E-15	2.532E-16	1.335E-16	3.049E-17	8.089E-18
0.30	3.534E-16	5.454E-17	9.135E-17	1.800E-17	9.333E-18	2.145E-18	6.009E-19
0.20	1.852E-18	1.751E-19	2.252E-19	4.354E-20	2.249E-20	5.201E-21	1.338E-21

Notes:

(1) Dose rate a 1-meter from package surface is evaluated for nonexclusive use shipments. The dose rate at 1-meter from the side of the package bounds the dose rate at 1-meter from the top and bottom of the package based on inspection of the package surface dose rates. Therefore, 1-meter dose rates on the ends of the package are not reported.

Table 5.5-4 – [redacted] NCT Neutron Dose Rate Summary

Energy (MeV)	Dose Rates [(mSv/hr)*(s/emitted n)]						
	Package Surface			Vehicle Surface	1-Meter	2-Meter	Driver Cab
	Top	Bottom	Side	Side	Side(1)	Side	
20.00	1.971E-08	1.185E-08	3.180E-08	7.308E-09	4.014E-09	9.383E-10	2.557E-10
15.00	1.649E-08	9.907E-09	2.619E-08	5.989E-09	3.303E-09	7.940E-10	2.069E-10
10.00	1.263E-08	7.680E-09	1.995E-08	4.537E-09	2.490E-09	6.000E-10	1.604E-10
7.50	1.271E-08	7.753E-09	1.995E-08	4.537E-09	2.493E-09	6.000E-10	1.594E-10
5.00	1.271E-08	7.784E-09	1.991E-08	4.533E-09	2.493E-09	5.956E-10	1.583E-10
4.00	1.334E-08	8.192E-09	2.069E-08	4.778E-09	2.602E-09	6.274E-10	1.647E-10
3.00	1.334E-08	8.192E-09	2.069E-08	4.778E-09	2.602E-09	6.274E-10	1.647E-10
2.50	1.319E-08	8.087E-09	2.044E-08	4.708E-09	2.553E-09	5.990E-10	1.602E-10
2.25	1.305E-08	7.989E-09	2.048E-08	4.681E-09	2.572E-09	6.061E-10	1.600E-10
2.00	1.403E-08	8.635E-09	2.169E-08	5.007E-09	2.768E-09	6.519E-10	1.741E-10
1.75	1.403E-08	8.635E-09	2.169E-08	5.007E-09	2.768E-09	6.519E-10	1.741E-10
1.50	1.192E-08	7.641E-09	2.089E-08	4.807E-09	2.650E-09	6.387E-10	1.721E-10
1.25	1.100E-08	6.394E-09	1.654E-08	3.859E-09	2.092E-09	5.045E-10	1.408E-10
1.10	1.073E-08	6.372E-09	1.654E-08	3.821E-09	2.076E-09	5.045E-10	1.302E-10
1.00	1.384E-08	8.903E-09	2.231E-08	5.185E-09	2.826E-09	6.730E-10	1.803E-10
0.90	1.436E-08	8.962E-09	2.240E-08	5.185E-09	2.826E-09	6.741E-10	1.803E-10
0.80	1.436E-08	8.962E-09	2.304E-08	5.323E-09	2.918E-09	6.911E-10	1.904E-10
0.70	1.315E-08	8.267E-09	2.304E-08	5.323E-09	2.918E-09	6.911E-10	1.904E-10
0.60	1.187E-08	7.164E-09	1.970E-08	4.483E-09	2.465E-09	5.890E-10	1.549E-10
0.50	9.005E-09	5.736E-09	1.516E-08	3.491E-09	1.919E-09	4.521E-10	1.211E-10
0.40	7.761E-09	4.807E-09	1.237E-08	2.941E-09	1.594E-09	3.832E-10	1.057E-10
0.30	5.691E-09	3.461E-09	8.586E-09	1.998E-09	1.102E-09	2.615E-10	7.106E-11
0.20	3.467E-09	2.176E-09	5.301E-09	1.248E-09	6.762E-10	1.603E-10	4.221E-11
0.10	1.399E-09	9.369E-10	2.201E-09	5.221E-10	2.849E-10	6.644E-11	1.816E-11

Notes:

(1) Dose rate a 1-meter from package surface is evaluated for nonexclusive use shipments. The dose rate at 1-meter from the side of the package bounds the dose rate at 1-meter from the top and bottom of the package based on inspection of the package surface dose rates. Therefore, 1-meter dose rates on the ends of the package are not reported.

Table 5.5-5 [redacted] NCT Gamma Dose Rate Summary

Energy (MeV)	Dose Rates [(mSv/hr)*(s/emitted γ)]						
	Package Surface			Vehicle Surface	1-Meter	2-Meter	Driver Cab
	Top	Bottom	Side	Side	Side[(1)]	Side	
12.00	1.166E-11	1.163E-11	2.631E-11	6.460E-12	3.638E-12	9.314E-13	2.696E-13
10.00	1.043E-11	1.046E-11	2.354E-11	5.775E-12	3.289E-12	8.239E-13	2.349E-13
8.00	9.074E-12	9.054E-12	2.048E-11	4.968E-12	2.834E-12	7.188E-13	2.008E-13
6.00	7.088E-12	7.132E-12	1.606E-11	3.879E-12	2.218E-12	5.478E-13	1.569E-13
4.00	4.090E-12	4.203E-12	9.308E-12	2.209E-12	1.218E-12	3.032E-13	8.804E-14
3.00	2.269E-12	2.427E-12	5.159E-12	1.202E-12	6.592E-13	1.656E-13	4.571E-14
2.50	1.428E-12	1.557E-12	3.222E-12	7.423E-13	4.043E-13	1.011E-13	2.867E-14
2.00	7.128E-13	8.070E-13	1.620E-12	3.625E-13	1.961E-13	4.926E-14	1.432E-14
1.80	4.914E-13	5.699E-13	1.115E-12	2.464E-13	1.347E-13	3.278E-14	9.248E-15
1.50	2.397E-13	2.923E-13	5.411E-13	1.186E-13	6.369E-14	1.578E-14	4.296E-15
1.34	1.466E-13	1.817E-13	3.309E-13	7.066E-14	3.825E-14	9.710E-15	2.659E-15
1.20	8.751E-14	1.125E-13	1.969E-13	4.175E-14	2.243E-14	5.336E-15	1.410E-15
1.00	3.484E-14	4.700E-14	7.848E-14	1.637E-14	8.653E-15	2.025E-15	5.672E-16
0.90	1.976E-14	2.793E-14	4.474E-14	9.160E-15	4.890E-15	1.173E-15	3.071E-16
0.80	1.024E-14	1.495E-14	2.287E-14	4.613E-15	2.461E-15	5.818E-16	1.659E-16
0.70	4.639E-15	7.110E-15	1.039E-14	2.080E-15	1.090E-15	2.617E-16	6.501E-17
0.67	3.530E-15	5.491E-15	7.928E-15	1.568E-15	8.272E-16	2.003E-16	5.013E-17
0.60	1.727E-15	2.805E-15	3.837E-15	7.541E-16	3.989E-16	9.185E-17	2.481E-17
0.50	4.751E-16	8.250E-16	1.044E-15	2.037E-16	1.057E-16	2.377E-17	6.568E-18
0.40	7.682E-17	1.470E-16	1.660E-16	3.189E-17	1.648E-17	3.744E-18	1.040E-18
0.30	3.887E-18	8.785E-18	8.224E-18	1.550E-18	8.021E-19	1.811E-19	4.929E-20
0.20	4.463E-21	1.426E-20	8.704E-21	1.619E-21	8.382E-22	1.922E-22	5.194E-23

Notes:

(1) Dose rate a 1-meter from package surface is evaluated for nonexclusive use shipments. The dose rate at 1-meter from the side of the package bounds the dose rate at 1-meter from the top and bottom of the package based on inspection of the package surface dose rates. Therefore, 1-meter dose rates on the ends of the package are not reported.

Table 5.5-6 – [redacted]NP NCT Neutron Dose Rate Summary

Energy (MeV)	Dose Rates [(mSv/hr)*(s/emitted n)]						
	Package Surface			Vehicle Surface	1-Meter	2-Meter	Driver Cab
	Top	Bottom	Side	Side	Side[(1)]	Side	
20.00	1.378E-08	1.172E-08	2.911E-08	6.646E-09	3.643E-09	8.549E-10	2.342E-10
15.00	1.141E-08	9.739E-09	2.386E-08	5.464E-09	2.958E-09	7.164E-10	1.906E-10
10.00	8.734E-09	7.496E-09	1.819E-08	4.191E-09	2.267E-09	5.378E-10	1.473E-10
7.50	8.738E-09	7.556E-09	1.819E-08	4.191E-09	2.267E-09	5.378E-10	1.472E-10
5.00	8.777E-09	7.561E-09	1.809E-08	4.158E-09	2.286E-09	5.420E-10	1.472E-10
4.00	9.311E-09	7.977E-09	1.901E-08	4.367E-09	2.365E-09	5.598E-10	1.530E-10
3.00	9.311E-09	7.977E-09	1.901E-08	4.367E-09	2.365E-09	5.598E-10	1.530E-10
2.50	9.074E-09	7.876E-09	1.866E-08	4.310E-09	2.354E-09	5.497E-10	1.457E-10
2.25	9.088E-09	7.763E-09	1.858E-08	4.293E-09	2.322E-09	5.521E-10	1.484E-10
2.00	1.010E-08	8.717E-09	2.046E-08	4.792E-09	2.604E-09	6.254E-10	1.678E-10
1.75	1.010E-08	8.717E-09	2.046E-08	4.792E-09	2.604E-09	6.254E-10	1.678E-10
1.50	8.815E-09	7.694E-09	1.938E-08	4.475E-09	2.435E-09	5.870E-10	1.551E-10
1.25	7.292E-09	6.141E-09	1.490E-08	3.453E-09	1.896E-09	4.471E-10	1.233E-10
1.10	7.159E-09	6.113E-09	1.475E-08	3.419E-09	1.882E-09	4.471E-10	1.233E-10
1.00	1.018E-08	8.791E-09	2.081E-08	4.810E-09	2.626E-09	6.319E-10	1.666E-10
0.90	1.039E-08	8.900E-09	2.098E-08	4.899E-09	2.647E-09	6.319E-10	1.672E-10
0.80	1.039E-08	8.900E-09	2.182E-08	5.068E-09	2.770E-09	6.487E-10	1.817E-10
0.70	1.001E-08	8.457E-09	2.182E-08	5.068E-09	2.770E-09	6.487E-10	1.817E-10
0.60	8.638E-09	7.258E-09	1.832E-08	4.168E-09	2.286E-09	5.508E-10	1.483E-10
0.50	6.506E-09	5.700E-09	1.410E-08	3.232E-09	1.784E-09	4.167E-10	1.130E-10
0.40	5.586E-09	4.813E-09	1.166E-08	2.767E-09	1.518E-09	3.651E-10	9.863E-11
0.30	3.893E-09	3.415E-09	7.853E-09	1.836E-09	1.010E-09	2.386E-10	6.657E-11
0.20	2.338E-09	2.104E-09	4.820E-09	1.140E-09	6.226E-10	1.461E-10	3.946E-11
0.10	9.335E-10	8.677E-10	1.942E-09	4.600E-10	2.503E-10	5.873E-11	1.594E-11

Notes:

(1) Dose rate a 1-meter from package surface is evaluated for nonexclusive use shipments. The dose rate at 1-meter from the side of the package bounds the dose rate at 1-meter from the top and bottom of the package based on inspection of the package surface dose rates. Therefore, 1-meter dose rates on the ends of the package are not reported.

Table 5.5-7 – [redacted] NCT Gamma Dose Rate Summary

Energy (MeV)	Dose Rates [(mSv/hr)*(s/emitted γ)]						
	Package Surface			Vehicle Surface	1-Meter	2-Meter	Driver Cab
	Top	Bottom	Side	Side	Side(1)	Side	
12.00	7.621E-12	9.259E-12	1.217E-11	2.947E-12	1.659E-12	4.109E-13	1.134E-13
10.00	6.859E-12	8.284E-12	1.099E-11	2.657E-12	1.491E-12	3.729E-13	1.041E-13
8.00	5.962E-12	7.173E-12	9.532E-12	2.296E-12	1.286E-12	3.216E-13	9.012E-14
6.00	4.627E-12	5.588E-12	7.343E-12	1.759E-12	9.824E-13	2.426E-13	6.693E-14
4.00	2.602E-12	3.204E-12	3.976E-12	9.304E-13	5.126E-13	1.276E-13	3.475E-14
3.00	1.410E-12	1.755E-12	2.039E-12	4.683E-13	2.555E-13	6.271E-14	1.798E-14
2.50	8.605E-13	1.089E-12	1.187E-12	2.670E-13	1.454E-13	3.576E-14	9.763E-15
2.00	4.171E-13	5.330E-13	5.353E-13	1.172E-13	6.354E-14	1.523E-14	4.217E-15
1.80	2.819E-13	3.653E-13	3.491E-13	7.576E-14	4.076E-14	9.789E-15	2.700E-15
1.50	1.327E-13	1.758E-13	1.519E-13	3.228E-14	1.719E-14	4.218E-15	1.138E-15
1.34	7.880E-14	1.054E-13	8.556E-14	1.790E-14	9.542E-15	2.269E-15	6.176E-16
1.20	4.564E-14	6.239E-14	4.717E-14	9.686E-15	5.157E-15	1.225E-15	3.308E-16
1.00	1.741E-14	2.418E-14	1.625E-14	3.269E-15	1.730E-15	4.040E-16	1.084E-16
0.90	9.666E-15	1.365E-14	8.484E-15	1.683E-15	8.882E-16	2.070E-16	5.655E-17
0.80	4.826E-15	6.957E-15	3.926E-15	7.667E-16	4.045E-16	9.341E-17	2.512E-17
0.70	2.092E-15	3.081E-15	1.571E-15	3.033E-16	1.584E-16	3.630E-17	9.762E-18
0.67	1.569E-15	2.337E-15	1.144E-15	2.210E-16	1.151E-16	2.668E-17	7.058E-18
0.60	7.419E-16	1.125E-15	5.004E-16	9.531E-17	4.961E-17	1.143E-17	3.108E-18
0.50	1.914E-16	2.992E-16	1.121E-16	2.099E-17	1.091E-17	2.497E-18	6.827E-19
0.40	2.826E-17	4.627E-17	1.363E-17	2.510E-18	1.301E-18	2.917E-19	7.754E-20
0.30	1.236E-18	2.203E-18	4.345E-19	7.840E-20	4.071E-20	9.148E-21	2.411E-21
0.20	1.015E-21	2.156E-21	1.673E-22	3.000E-23	1.541E-23	3.419E-24	9.873E-25

Notes:

(1) Dose rate a 1-meter from package surface is evaluated for nonexclusive use shipments. The dose rate at 1-meter from the side of the package bounds the dose rate at 1-meter from the top and bottom of the package based on inspection of the package surface dose rates. Therefore, 1-meter dose rates on the ends of the package are not reported.

Table 5.5-8 – [redacted] NCT Neutron Dose Rate Summary

Energy (MeV)	Dose Rates [(mSv/hr)*(s/emitted n)]						
	Package Surface			Vehicle Surface	1-Meter	2-Meter	Driver Cab
	Top	Bottom	Side	Side	Side(1)	Side	
20.00	1.138E-08	1.237E-08	2.497E-08	5.700E-09	3.137E-09	7.383E-10	2.030E-10
15.00	9.438E-09	1.026E-08	2.033E-08	4.702E-09	2.566E-09	6.052E-10	1.642E-10
10.00	7.277E-09	7.909E-09	1.550E-08	3.595E-09	1.952E-09	4.628E-10	1.327E-10
7.50	7.313E-09	8.016E-09	1.550E-08	3.595E-09	1.952E-09	4.697E-10	1.313E-10
5.00	7.367E-09	8.036E-09	1.547E-08	3.594E-09	1.976E-09	4.697E-10	1.307E-10
4.00	7.820E-09	8.457E-09	1.618E-08	3.773E-09	2.066E-09	5.000E-10	1.359E-10
3.00	7.820E-09	8.457E-09	1.618E-08	3.773E-09	2.066E-09	5.000E-10	1.359E-10
2.50	7.639E-09	8.279E-09	1.583E-08	3.662E-09	2.014E-09	4.875E-10	1.345E-10
2.25	7.630E-09	8.218E-09	1.582E-08	3.662E-09	2.019E-09	4.907E-10	1.288E-10
2.00	8.560E-09	9.364E-09	1.771E-08	4.160E-09	2.324E-09	5.701E-10	1.467E-10
1.75	8.560E-09	9.364E-09	1.771E-08	4.160E-09	2.324E-09	5.701E-10	1.467E-10
1.50	7.359E-09	8.227E-09	1.708E-08	3.976E-09	2.154E-09	5.294E-10	1.378E-10
1.25	6.029E-09	6.476E-09	1.254E-08	2.949E-09	1.624E-09	3.948E-10	1.033E-10
1.10	5.909E-09	6.365E-09	1.243E-08	2.880E-09	1.587E-09	3.876E-10	1.031E-10
1.00	8.649E-09	9.387E-09	1.823E-08	4.296E-09	2.355E-09	5.649E-10	1.526E-10
0.90	8.858E-09	9.661E-09	1.831E-08	4.356E-09	2.363E-09	5.649E-10	1.526E-10
0.80	8.858E-09	9.661E-09	1.980E-08	4.567E-09	2.508E-09	5.965E-10	1.643E-10
0.70	8.415E-09	9.210E-09	1.980E-08	4.567E-09	2.508E-09	5.965E-10	1.643E-10
0.60	7.227E-09	7.792E-09	1.619E-08	3.711E-09	2.021E-09	4.793E-10	1.319E-10
0.50	5.478E-09	6.095E-09	1.229E-08	2.857E-09	1.582E-09	3.702E-10	1.001E-10
0.40	4.684E-09	5.254E-09	1.012E-08	2.446E-09	1.360E-09	3.308E-10	8.782E-11
0.30	3.232E-09	3.660E-09	6.685E-09	1.587E-09	8.767E-10	2.012E-10	6.022E-11
0.20	1.938E-09	2.244E-09	4.003E-09	9.689E-10	5.269E-10	1.257E-10	3.446E-11
0.10	7.594E-10	9.000E-10	1.563E-09	3.801E-10	2.048E-10	4.800E-11	1.324E-11

Notes:

(1) Dose rate a 1-meter from package surface is evaluated for nonexclusive use shipments. The dose rate at 1-meter from the side of the package bounds the dose rate at 1-meter from the top and bottom of the package based on inspection of the package surface dose rates. Therefore, 1-meter dose rates on the ends of the package are not reported.

Table 5.5-9 – [redacted] HAC Gamma Dose Rate Summary

Energy (MeV)	Dose Rates [(mSv/hr)*(s/emitted γ)]		
	1-Meter		
	Top	Bottom	Side
12.00	4.571E-12	5.445E-12	4.841E-12
10.00	4.093E-12	4.916E-12	4.398E-12
8.00	3.498E-12	4.196E-12	3.781E-12
6.00	2.680E-12	3.267E-12	2.905E-12
4.00	1.467E-12	1.800E-12	1.607E-12
3.00	7.714E-13	9.533E-13	8.517E-13
2.50	4.579E-13	5.743E-13	5.063E-13
2.00	2.121E-13	2.691E-13	2.417E-13
1.80	1.414E-13	1.801E-13	1.617E-13
1.50	6.260E-14	8.398E-14	7.363E-14
1.34	3.752E-14	4.962E-14	4.340E-14
1.20	2.101E-14	2.796E-14	2.494E-14
1.00	7.559E-15	1.061E-14	9.191E-15
0.90	4.125E-15	5.893E-15	5.043E-15
0.80	2.015E-15	2.918E-15	2.486E-15
0.70	8.492E-16	1.261E-15	1.085E-15
0.67	6.439E-16	9.440E-16	8.087E-16
0.60	2.930E-16	4.538E-16	3.795E-16
0.50	7.429E-17	1.165E-16	9.703E-17
0.40	1.059E-17	1.760E-17	1.434E-17
0.30	4.473E-19	8.067E-19	6.269E-19
0.20	3.533E-22	7.517E-22	5.211E-22

Table 5.5-10 – [redacted] HAC Neutron Dose Rate Summary

Energy (MeV)	Dose Rates [(mSv/hr)*(s/emitted n)]		
	1-Meter		
	Top	Bottom	Side
20.00	5.774E-09	6.387E-09	6.275E-09
15.00	4.624E-09	5.135E-09	5.118E-09
10.00	3.438E-09	3.812E-09	3.798E-09
7.50	3.438E-09	3.812E-09	3.798E-09
5.00	3.374E-09	3.743E-09	3.792E-09
4.00	3.520E-09	3.903E-09	3.928E-09
3.00	3.520E-09	3.903E-09	3.928E-09
2.50	3.431E-09	3.807E-09	3.811E-09
2.25	3.534E-09	3.870E-09	3.894E-09
2.00	3.727E-09	4.190E-09	4.191E-09
1.75	3.874E-09	4.416E-09	4.295E-09
1.50	3.874E-09	4.416E-09	4.295E-09
1.25	2.812E-09	3.048E-09	3.068E-09
1.10	2.796E-09	3.028E-09	3.066E-09
1.00	3.943E-09	4.379E-09	4.329E-09
0.90	3.943E-09	4.379E-09	4.329E-09
0.80	4.542E-09	5.040E-09	4.929E-09
0.70	4.542E-09	5.040E-09	4.929E-09
0.60	3.825E-09	4.164E-09	4.116E-09
0.50	2.563E-09	2.916E-09	2.868E-09
0.40	2.043E-09	2.276E-09	2.256E-09
0.30	1.455E-09	1.666E-09	1.647E-09
0.20	8.025E-10	9.399E-10	9.369E-10
0.10	3.166E-10	3.799E-10	3.779E-10

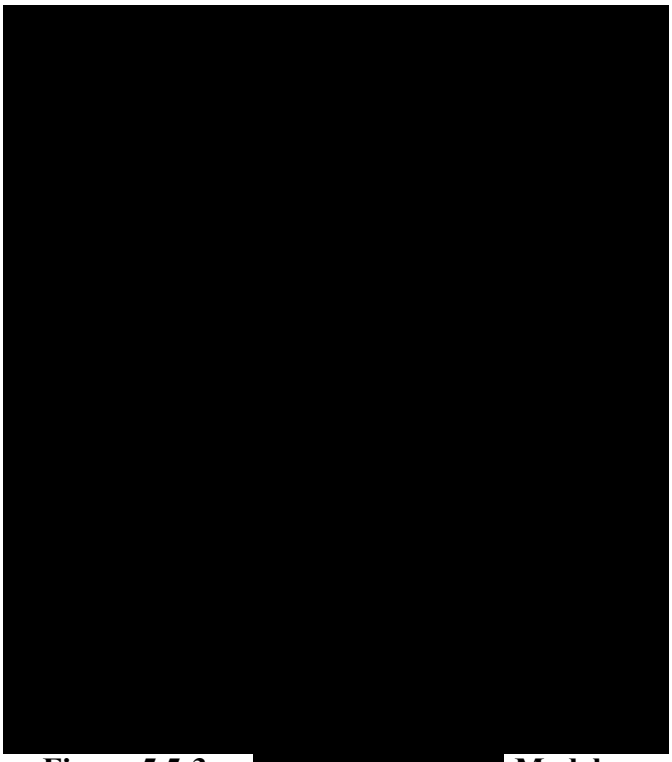


Figure 5.5-3 – [redacted] Model

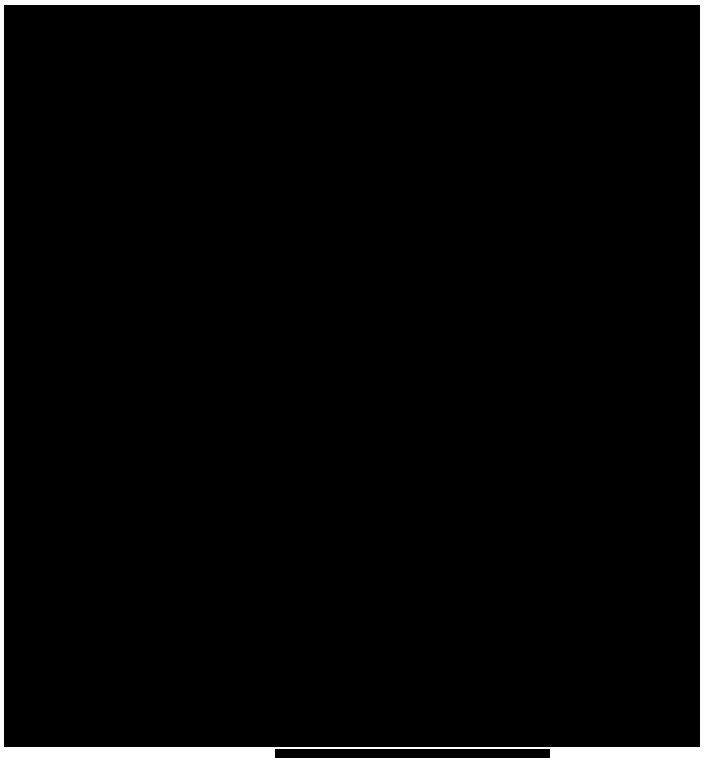


Figure 5.5-4 – [redacted] Model

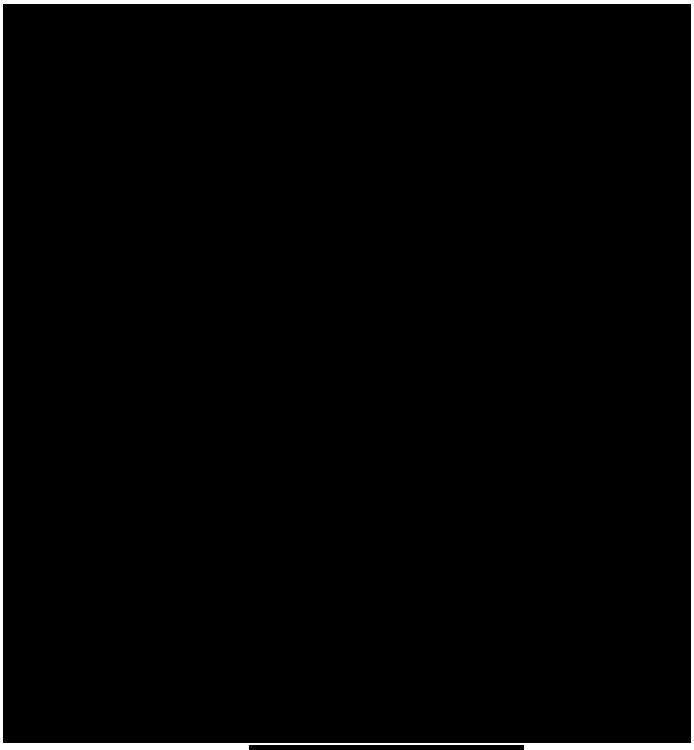
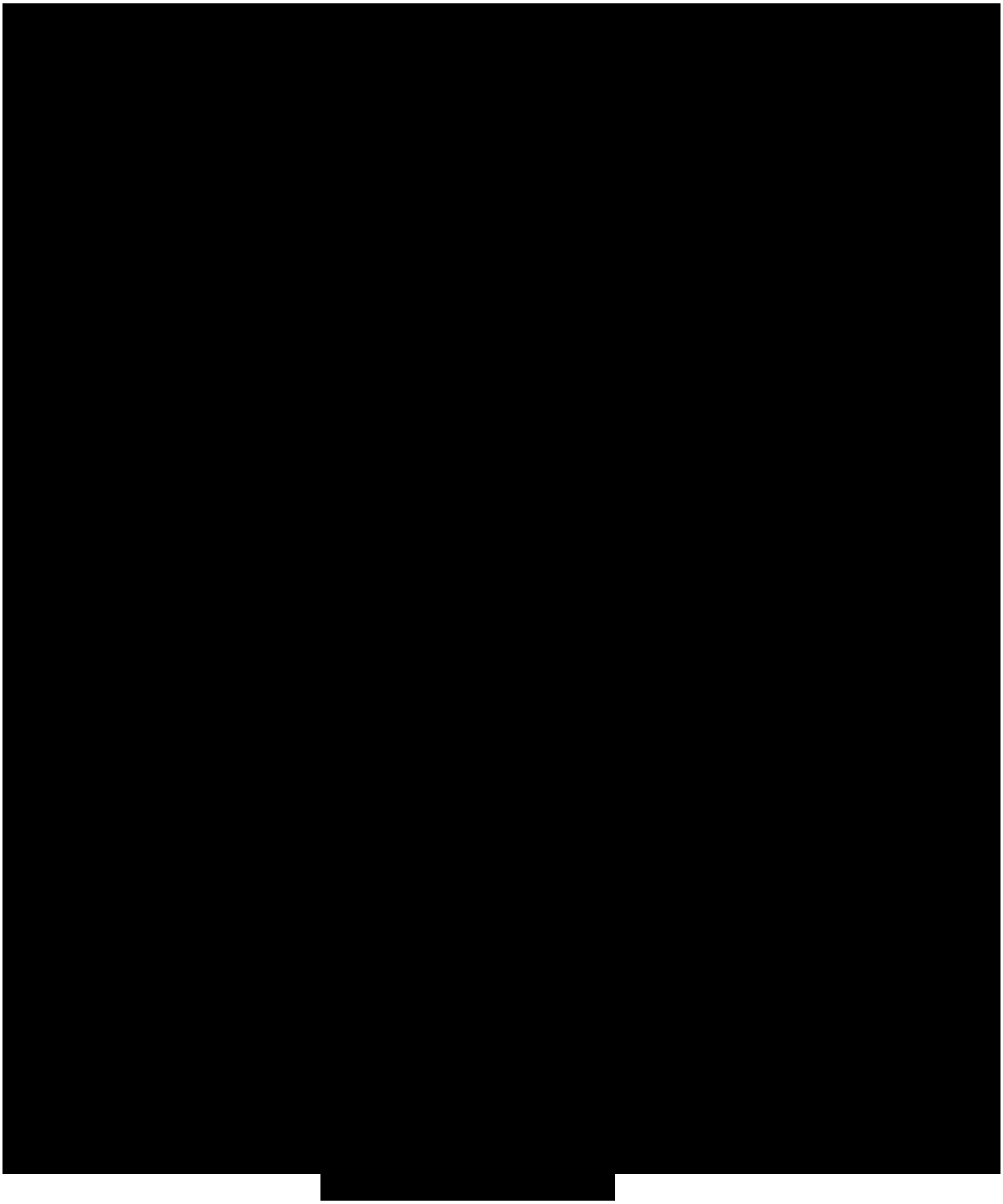


Figure 5.5-5 – [redacted] Model



5.5.4 Irradiated CANDU Fuel and Hardware Waste Shielding Analysis

This appendix outlines the shielding analysis demonstrating compliance with the dose rate limits of 10 CFR 71 for transporting irradiated CANDU fuel waste (Content 2-2), defined as irradiated CANDU fuel contents and irradiated hardware waste contents. The analysis and content limits outlined are based on the irradiated fuel from the Gentilly-1 (G1) reactor but are applicable to all CANDU fuel waste that satisfies the bounding parameters evaluated. The G1 reactor was a 250 MWe reactor design that went into service in 1971 and operated intermittently until 1979. The maximum burnup of the G1 CANDU fuel contents is 4.683 GWd/MTU. The bundle design of the G1 fuel is shown in Figure 5.5-7. The G1 fuel is comprised of natural UO_2 fuel with all Zircaloy cladding and bundle structure. The G1 fuel is currently stored in baskets that contain up to 38 fuel bundles. No structural analysis is credited for the baskets, so for dose rate calculations, failure of the basket and a bounding reconfiguration of the contents is assumed. Two baskets can fit into the CCV cavity at once, so the maximum quantity of irradiated fuel transported is 76 total fuel bundles. Additionally, there are some baskets that contain only irradiated hardware from the reactor operation. The hardware in these baskets may include irradiated stainless steel, Inconel, and/or Zircaloy components used to string the fuel bundles together (e.g. stainless steel flux suppressors, Zircaloy central structural tubes, and Inconel springs).

Based on the G1 fuel contents and the accompanying shielding analysis, the irradiated CANDU fuel content limits are outlined in Table 5.5-11. While the CANDU fuel limits in Table 5.5-11 may be applied to irradiated natural CANDU fuel contents from reactors other than G1, the irradiated hardware limits are specifically based on G1 fuel hardware, as the source terms are specific to the irradiation history and cooling time of these contents. The package may be loaded with either the standard baskets containing irradiated CANDU fuel or the special baskets containing G1 hardware but mixing both basket types in the same package is not permissible. The irradiated hardware mass limits are specified per package. Additionally, the specified limits allow for the standard two OPTIMUS®-H packages per shipment.

For this irradiated CANDU fuel waste analysis, the shielding design and model for the OPTIMUS®-H packaging are identical to the base analysis outlined in Sections 5.2 and 5.4. The following subsections outline the source specification and shielding evaluation specific to the CANDU fuel contents. As a result of the shielding evaluation for the CANDU fuel contents, the maximum radiation levels for these contents are provided in Table 5.5-12. Note that the vehicle surface and 2-meter dose rates listed are conservatively calculated for two packages on the vehicle. The decay heats listed in Table 5.5-12 are bounding values for each case based on a maximum load. The decay heats of the actual contents are expected to be well below this

quantity and will be determined for each load individually prior to shipment for thermal requirements. Based on this shielding analysis, the irradiated CANDU fuel contents are handled differently than the standard TRU waste or irradiated fuel waste contents analyzed in this chapter. Dose rates in this appendix are calculated for a bounding case, so no additional calculations are required for demonstrating compliance with the regulatory dose rate limits (i.e. the CANDU contents are exempt from the dose rate compliance calculations outlined in Section 5.4.4.3). Based on the restrictions on the contents listed in Table 5.5-11, the external dose rates for the irradiated CANDU fuel and G1 hardware contents in the OPTIMUS®-H will not exceed the regulatory dose rate limits.

5.5.4.1 CANDU Fuel and G1 Hardware Source Specification

To calculate the source terms for this analysis, the [redacted] The medium considered for the generation of all secondary particles (neutrons from α-n reactions and Bremsstrahlung photons) is a UO_2 matrix. The resulting source terms are grouped into the generic photon and neutron group structures shown in Table 5.2-1 and Table 5.2-2, respectively.

For the fuel source term calculation, the maximum reported specific power of the G1 reactor (23.3 MW/MTU) is used along with a calculated operating time (215 days) to equate to the maximum burnup (5 GWd/MTU). Note that no realistic variation in the specific power and operation resulting in the 5 GWd/MTU final burnup will have a significant effect on the resulting source term, especially with the longer 40-year cooling time. [redacted] The neutron and photon source terms for the CANDU fuel contents are presented in the generic grouping structure in Table 5.5-13 and Table 5.5-14, respectively. The bounding heat load per assembly, as determined by the source term calculation, is 1.715 W/assembly. This corresponds to a bounding total heat load of 130.4 W for 76 assemblies at the maximum burnup and minimum cool time.

[redacted] The operating history of the G1 reactor is shown in Table 5.5-21. The cooling time listed for each year is the number of days necessary for the irradiation time of the following year to fall at the end of the year. [redacted]

5.5.4.2 CANDU Fuel and G1 Hardware Shelding Evaluation

[redacted]

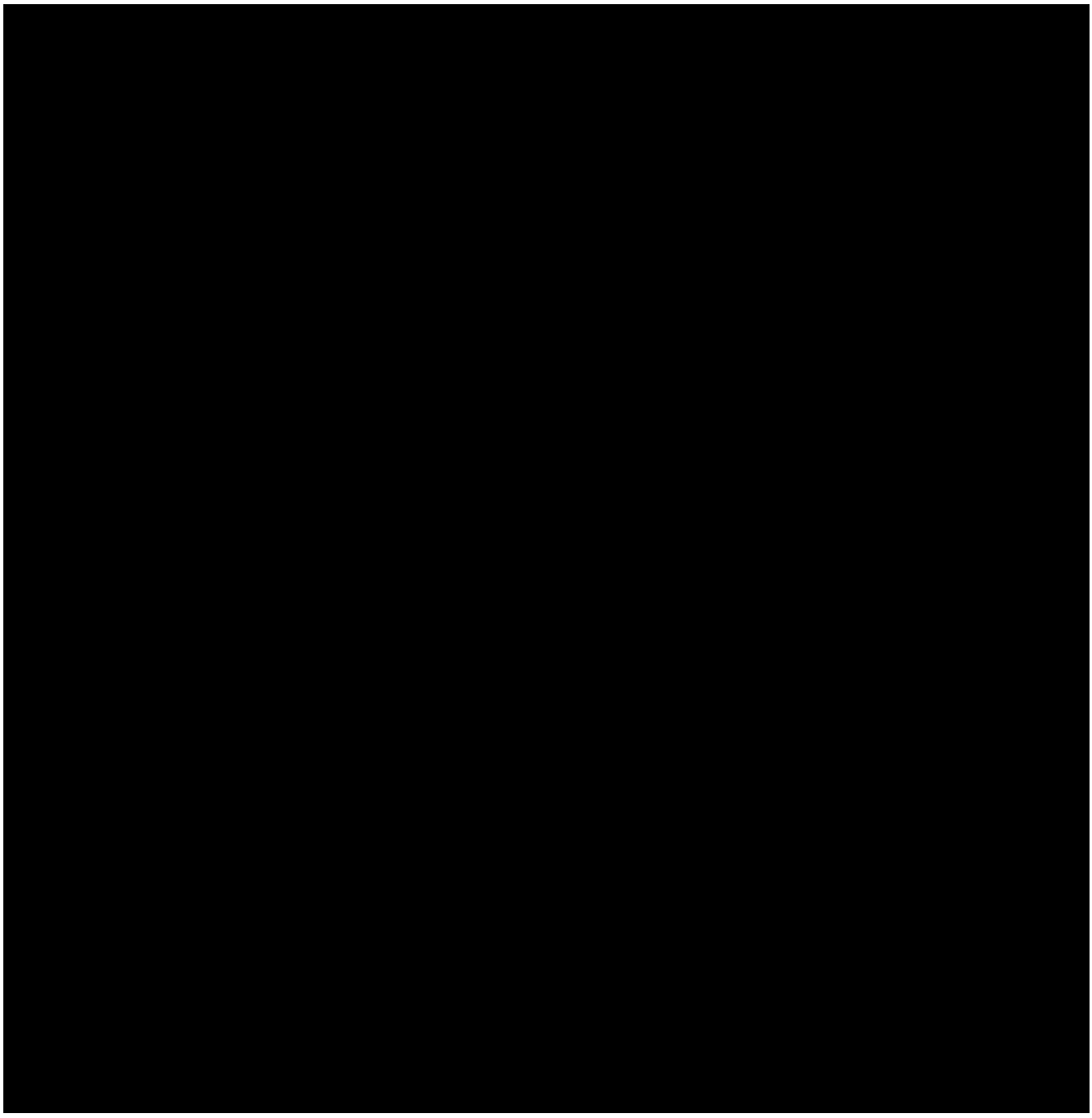


Table 5.5-11 – CANDU Fuel Content Restrictions

[redacted]

Table 5.5-12 – CANDU Fuel Content Maximum Radiation Levels

[redacted]

Table 5.5-13 – CANDU Fuel Neutron Source

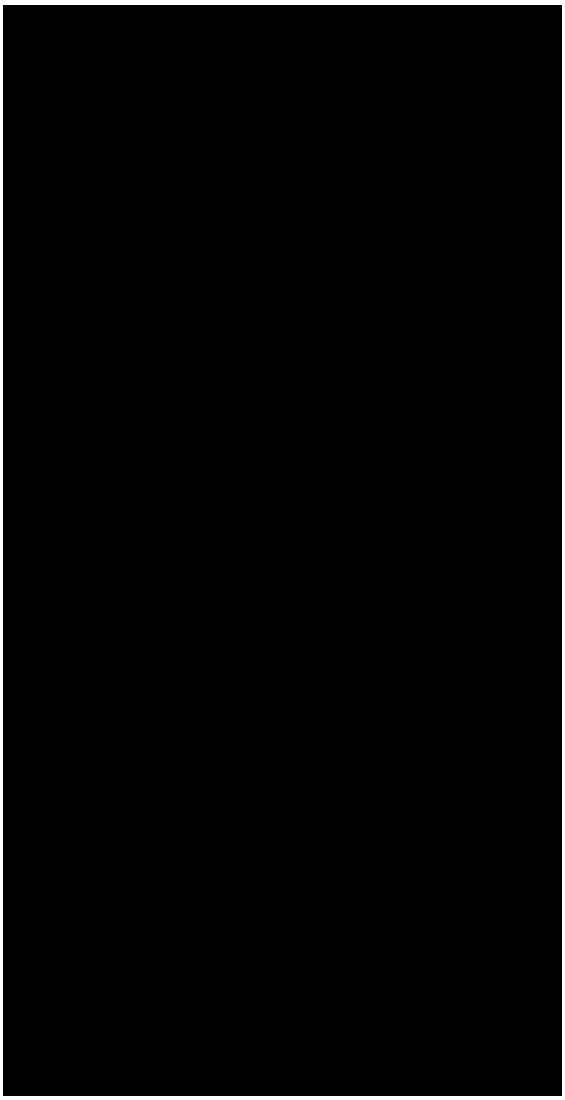


Table 5.5-14 – CANDU Fuel Photon Source

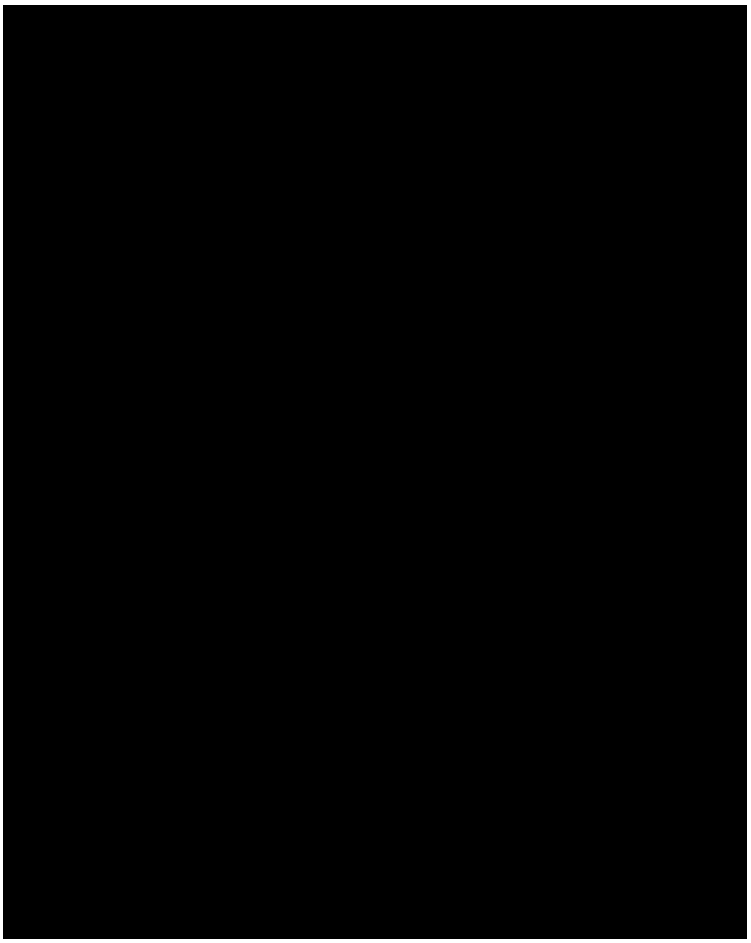


Table 5.5-15 – G1 Hardware Exposure History

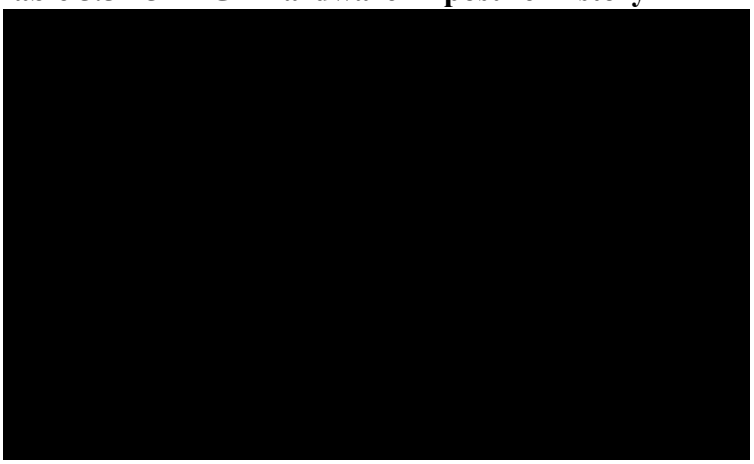


Table 5.5-16 – G1 Hardware Cobalt Impurities and Cobalt-60 Content

[redacted]

Table 5.5-17 – CANDU Fuel and G1 Hardware [redacted] Content Material Compositions

[redacted]

Table 5.5-18 – G1 Hardware Case Activities

[redacted]

Table 5.5-19 – CANDU Fuel and G1 Hardware Case Dose Rate Results

[redacted]

Figure 5.5-7 – G1 Fuel Bundle Design

Figure 5.5-8 – CANDU Fuel Case Shielding Model

Figure 5.5-9 – G1 Hardware Case Shielding Models (L – Zirc / M – Steel / R – Inconel)

Figure 5.5-10 – G1 Combined Hardware Case Shielding Model

Chapter 6
Criticality Evaluation

Table of Contents

6 CRITICALITY EVALUATION 6-1

6.1 Description of Criticality Design 6.1-1
6.1.1 Design Features 6.1-1
6.1.2 Summary Table of Criticality Evaluation 6.1-1
6.1.3 Criticality Safety Index 6.1-1

6.2 Package Contents 6.2-1
6.2.1 FGE Cases 6.2-1
6.2.2 FEM Cases 6.2-2

6.3 General Considerations 6.3-1
6.3.1 Model Configuration 6.3-1
6.3.2 Material Properties 6.3-6
6.3.3 Computer Codes and Cross-Section Libraries 6.3-10
6.3.4 Demonstration of Maximum Reactivity 6.3-10

6.4 Single Package Evaluation 6.4-1
6.4.1 FGE Single Package Configuration 6.4-1
6.4.2 FGE Single Package Summary Results 6.4-1
6.4.3 FEM Single Package Configuration 6.4-7
6.4.4 FEM Single Package Summary Results 6.4-8

6.5 Evaluation of Package Arrays Under Normal Conditions of Transport 6.5-1

6.6 Package Arrays Under Hypothetical Accident Conditions 6.6-1
6.6.1 FGE HAC Package Array Configuration 6.6-1
6.6.2 FGE HAC Package Array Results 6.6-1
6.6.3 FEM HAC Package Array Configuration 6.6-9
6.6.4 FEM HAC Package Array Summary Results 6.6-9

6.7 Fissile Material Packages for Air Transport 6.7-1

6.8 Benchmark Evaluation 6.8-1
6.8.1 Applicability of Benchmark Experiments 6.8-1
6.8.2 Bias Determination 6.8-5

6.9 Appendix 6.9-1
6.9.1 References 6.9-1

List of Figures

Figure 6.3-1 [redacted] Criticality Model – Package Geometry 6.3-4
Figure 6.3-2 Baseline Package Array Model..... 6.3-5
Figure 6.3-3 Single Package Model..... 6.3-5
Figure 6.3-4 FGE Fissile Sphere Positions..... 6.3-17
Figure 6.3-5 FGE Fissile Sphere Positioning for Package Arrays 6.3-17
Figure 6.3-6 Floodable Regions: [redacted] 6.3-17
Figure 6.3-7 FEM Fissile Homogeneous Cases 6.3-18
Figure 6.3-8 FEM Fissile Heterogeneous Cylinder Cases..... 6.3-18
Figure 6.3-9 FEM Fissile Heterogeneous Sphere Cases 6.3-19
Figure 6.4-1 Effect of H/^{239}Pu on k_{eff} for Several ^{239}Pu masses – FGE-1 Single Package 6.4-5
Figure 6.4-2 Effect of Be Removal on k_{eff} – FGE-1 Single Package 6.4-5
Figure 6.4-3 FEM-1, Sphere Particle, Hex Array – Single Package 6.4-13
Figure 6.4-4 FEM-1, Cylinder Particle, Hex Array - Single Package..... 6.4-14
Figure 6.4-5 FEM-1 and 2, Cylinder Particle, Hex Array Comparison - Single Package... 6.4-14
Figure 6.6-1 Effect of H/^{239}Pu on k_{eff} for Several ^{239}Pu masses – FGE-1 HAC Package Array 6.6-5
Figure 6.6-2 Flooded H/Pu Iteration H/^{239}Pu Curve – FGE-1 HAC Package Array 6.6-5
Figure 6.6-3 Effect of Be Removal on k_{eff} – FGE-1 HAC Package Array..... 6.6-6
Figure 6.6-4 FEM-1, Sphere Particle, Hex Array - HAC Package Array 6.6-13
Figure 6.6-5 FEM-1, Cylinder Particle, Hex Array - HAC Package Array 6.6-13
Figure 6.6-6 FEM-1 and 2, Cylinder Particle, Hex Array Comparison - HAC Package Array 6.6-17
Figure 6.8-1 USLSTATS Plot of k_{norm} vs. EALF –Plutonium Solution Systems without Beryllium Reflector 6.8-18
Figure 6.8-2 USLSTATS Plot of k_{eff} vs. H/(^{239}Pu + ^{241}Pu) – Plutonium Systems without Beryllium Reflector 6.8-18
Figure 6.8-3 USLSTATS Plot of k_{eff} vs. Fissile Weight Percent – Plutonium Solution Systems without Beryllium Reflector 6.8-19
Figure 6.8-4 USLSTATS Plot of k_{norm} vs. EALF –Plutonium Solution Systems with Beryllium Reflector..... 6.8-19
Figure 6.8-5 USLSTATS Trend Plot of k_{eff} vs. H/(^{239}Pu + ^{241}Pu) –Plutonium Systems with Beryllium Reflector 6.8-20
Figure 6.8-6 USLSTATS Trend Plot of k_{eff} vs. Fissile Weight Percent –Plutonium Solution Systems with Beryllium Reflector..... 6.8-20
Figure 6.8-7 USLSTATS Plot of k_{norm} vs. EALF – Low-Enriched Uranium Systems 6.8-21
Figure 6.8-8 USLSTATS Plot of k_{norm} vs. H/^{235}U – Low-Enriched Uranium Systems..... 6.8-21
Figure 6.8-9 USLSTATS Plot of k_{norm} vs. ^{235}U Weight Percent – Low-Enriched Uranium Systems 6.8-22

List of Tables

Table 6.1-1 Summary Table of FGE Criticality Evaluations 6.1-2
Table 6.1-2 Summary Table of FEM Criticality Evaluations 6.1-3
Table 6.2-1 Fissile Gram Equivalent Waste Content Cases 6.2-3
Table 6.2-2 Fissile Equivalent Mass Waste Content Cases 6.2-3
Table 6.2-3 Fissile Gram Equivalent Waste Content Case Description 6.2-4
Table 6.2-4 Fissile Equivalent Mass Waste Content Case Description 6.2-4
Table 6.3-1 Primary MCNP Model Package Dimensions 6.3-3
Table 6.3-2 Nuclear Properties of [redacted] Stainless Steel 6.3-7
Table 6.3-3 Nuclear Properties of [redacted] 6.3-8
Table 6.3-4 Nuclear Properties of Materials 6.3-9
Table 6.3-5 Heterogeneous Fissile Content Model Parameters 6.3-16
Table 6.3-6 FGE Conversion Factors 6.3-16
Table 6.4-1 Mass Limit for FGE Cases - Single Package 6.4-3
Table 6.4-2 FGE-1 Baseline Configuration – Single Package 6.4-3
Table 6.4-3 FGE-1 Fissile Sphere Position – Single Package 6.4-3
Table 6.4-4 FGE-1 Flooding Configuration– Single Package 6.4-4
Table 6.4-5 FGE-1 Effect of Be Removal from Moderator and Reflector– Single Package 6.4-4
Table 6.4-6 Limits for FEM Cases - Single Package 6.4-10
Table 6.4-7 FEM-1, Sphere Particle Baseline Configuration – Single Package 6.4-10
Table 6.4-8 FEM-1, Cylinder Particle Baseline Configuration – Single Package 6.4-10
Table 6.4-9 FEM-2, Sphere Particle Baseline Configuration - Single Package 6.4-11
Table 6.4-10 FEM-2, Cylinder Particle Baseline Configuration - Single Package 6.4-11
Table 6.4-11 FEM-2, Homogeneous Fissile Volume Configuration - Single Package 6.4-12
Table 6.6-1 Mass Limit Cases for FGE Cases - HAC Package Array 6.6-3
Table 6.6-2 FGE-1 Baseline Configuration - HAC Package Array 6.6-3
Table 6.6-3 FGE-1 Fissile Sphere Position – HAC Package Array 6.6-3
Table 6.6-4 FGE-1 Flooding Configuration– HAC Package Array 6.6-4
Table 6.6-5 FGE-1 Flooded H/Pu Iteration Effect on H/^{239}Pu– HAC Package Array 6.6-4
Table 6.6-6 FGE-1 Effect of Be Removal from Moderator and Reflector– HAC Package Array 6.6-4
Table 6.6-7 Limits for FEM Cases - HAC Package Array 6.6-11
Table 6.6-8 FEM-1, Sphere Particle Baseline Configuration - HAC Package Array 6.6-11
Table 6.6-9 FEM-1, Cylinder Particle Baseline Configuration - HAC Package Array 6.6-12
Table 6.6-10 FEM-1, Cylinder Particle Flooding Configuration - HAC Package Array 6.6-12
Table 6.6-11 FEM-2, Sphere Particle Baseline Configuration - HAC Package Array 6.6-15
Table 6.6-12 FEM-2, Cylinder Particle Baseline Configuration - HAC Package Array 6.6-15
Table 6.6-13 FEM-2, Sphere Particle Flooding Configuration - HAC Package Array 6.6-15
Table 6.6-14 FEM-2, Cylinder Particle Flooding Configuration - HAC Package Array 6.6-16
Table 6.6-15 FEM-1, Homogeneous Fissile Volume Configuration - HAC Package Array 6.6-19
Table 6.6-16 FEM-1, Homogeneous Volume, Flooding Configuration - HAC Package Array 6.6-20
Table 6.8-1 Criticality Safety Bias and USL Functions 6.8-8
Table 6.8-2 FEM Criticality Safety USL Functions 6.8-8

Table 6.8-3 Summary of Critical Benchmark Experiments – Plutonium Cases 6.8-8
Table 6.8-4 Summary of Critical Benchmark Experiments – Low-Enriched Uranium Cases 6.8-9
Table 6.8-5 Plutonium Critical Experiment Area of Applicability 6.8-9
Table 6.8-6 Low-Enriched Uranium Critical Experiment Area of Applicability 6.8-10
Table 6.8-7 USL Functions for Plutonium without Beryllium Reflector Critical Solution Benchmarks..... 6.8-10
Table 6.8-8 USL Functions for Plutonium with Beryllium Reflector Critical Solution Benchmarks..... 6.8-10
Table 6.8-9 Applicable USL Functions for FGE Configurations 6.8-11
Table 6.8-10 USL Functions for Low-Enriched Uranium Critical Benchmarks 6.8-11
Table 6.8-11 USLSTATS Input for Plutonium Critical Benchmarks 6.8-12
Table 6.8-12 USLSTATS Input for Uranium Critical Benchmarks 6.8-15

6 CRITICALITY EVALUATION

This chapter presents the criticality evaluation that demonstrates that the OPTIMUS®-H package complies with the requirements of 10 CFR 71.55 and 10 CFR 71.59 for the contents specified in Section 1.2.2 and discussed in Section 6.2. Specifically, the criticality evaluation demonstrates compliance with the criticality requirements for intermediate level waste that satisfies the fissile gram equivalent (FGE) limits for ^{239}Pu specified in Table 1-1 and for irradiated fuel waste that satisfies the fissile equivalent mass (FEM) limits for ^{235}U specified in Table 1-3. The results of the criticality evaluation are summarized in Section 6.1.2.

No additional criticality evaluations are performed for the Shield Insert Assemblies (SIAs). Depending on the content, the use of the SIAs in the OPTIMUS®-H will have either a negligible or negative effect on the criticality of the system. The additional reflection provided by the SIAs is negligible, considering the reflection provided by the CCV and OSV of the bare cask. The use of the SIAs will only further restrict the geometric configuration of the fissile contents. Thus, the use of the SIAs is bounded by the bare cask, as analyzed in this chapter.

This page intentionally left blank.

6.1 Description of Criticality Design

6.1.1 Design Features

The packaging consists of the stainless steel inner Cask Containment Vessel (CCV), which contains the radioactive contents, surrounded by a ductile cast iron (DCI) Outer Shield Vessel (OSV). Impact limiters are affixed to the top and bottom of the OSV. The CCV is responsible for the containment credited in the analysis. [redacted]

6.1.2 Summary Table of Criticality Evaluation

6.1.2.1 Summary of FGE Criticality Evaluation

As shown in Table 6.1-1, all mass limits shown for each fissile gram equivalent (FGE) case have $k_{eff} + 2\sigma$ below their respective upper subcritical limit (USL) for the single package and HAC package array evaluations. Because infinitely large arrays are modeled and typically NCT arrays are 5N and HAC arrays are 2N, it follows that an infinitely large HAC package array with flooding is more reactive than an infinitely large unflooded NCT package array. Therefore, only HAC package arrays were analyzed. See Section 6.5 for further detail.

6.1.2.2 Summary of FEM Criticality Evaluation

As shown in Table 6.1-2, all most reactive cases for each fissile equivalent mass (FEM) case have $k_{eff} + 2\sigma$ below their respective USL for the single package and HAC package array evaluations. FEM-1 cases apply to a mixture with debris (e.g., particle/lump) size characteristic dimensions (i.e., diameter or thickness), such that the uranium enrichment does not exceed 0.96% ^{235}U and the particle sizes are limited to ≤0.05cm and/or ≥4.0cm radially. For waste mixtures of unlimited debris size characteristic dimensions, FEM-2 determined a reduced ^{235}U enrichment level of 0.80% ^{235}U, such that all debris dimensions are subcritical under the USL. The debris is evaluated as rods and spherical particles to cover intermediate level waste and irradiated fuel waste contents.

6.1.3 Criticality Safety Index

An infinite number of packages are analyzed in the package array evaluations. Per 10 CFR 71.59(b) [1], the criticality safety index (CSI) may be zero if an unlimited number of packages is subcritical, such that the value of "N" is effectively equal to infinity. Therefore, the CSI is 0.0.

Table 6.1-1 Summary Table of FGE Criticality Evaluations

FGE Case	^{239}Pu Mass (g)	Be VF	H/ ^{239}Pu	Package Configuration	Array Size	$k_{eff} + 2\sigma$	USL
FGE-1	335	0.01	900	Single Package	--	0.93474	0.9393
				HAC Array	Infinite	0.93669	
FGE-2a	350	0.01	900	Single Package	--	0.93718	0.9393
				HAC Array	Infinite	0.93850	
FGE-2b	370	0.01	900	Single Package	--	0.93501	0.9393
				HAC Array	Infinite	0.93751	
FGE-2c	390	0.01	1000	Single Package	--	0.93563	0.9393
			900	HAC Array	Infinite	0.93751	
FGE-3	121	0.01	800	Single Package	--	0.93534	0.9368
				HAC Array	Infinite	0.93545	
FGE-4	320	0.4	900	Single Package	--	0.93237	0.9368
				HAC Array	Infinite	0.93477	
FGE-5	245	0.0	900	Single Package	--	0.93308	0.9393
				HAC Array	Infinite	0.93699	

Table 6.1-2 Summary Table of FEM Criticality Evaluations

FEM Case	^{235}U enrichment (wt.%)	Particle Size Restriction	H/ ^{235}U	Package Configuration	Array Size	$k_{eff} + 2\sigma$	USL
FEM-1	0.96	≤ 0.05 cm and/or ≥ 4.0 cm radially	444	Single Package	--	0.93559	0.9414
				HAC Array	Infinite	0.90018	
FEM-2	0.80	unlimited	532	Single Package	--	0.93317	0.9414
				HAC Array	Infinite	0.93883	

This page intentionally left blank.

6.2 Package Contents

Content cases for the FGE and FEM waste are defined in Table 6.2-1 and Table 6.2-2, respectively. A ^{239}Pu FGE limit is determined for each plutonium waste content case listed and a ^{235}U wt.% FEM limit is determined for each uranium waste content case listed.

Manually compacted (i.e., not machine compacted) waste will be bounded by a 15% volumetric packing fraction for polyethylene. Report WP 08-PT.09 documents physical testing of manually compacted waste and determined a maximum polyethylene packing fraction of 13.36% [6.1]. The utilization of polyethylene as the bounding hydrogenous moderating material is justified by report SAIC-1322-001 [6.2], which concludes that polyethylene is the most reactive moderator that could credibly moderate the transuranic waste in a pure form.

Additionally, 1% by volume beryllium in the modeled waste matrix bounds the presence of up to 1 wt.% quantities of special reflectors that are randomly dispersed in the payload containers. As beryllium has a higher density than the other moderator materials (polyethylene and water), 1 vol% Be in this mixture equates to ~1.8 wt% and special reflectors are identified per report SAIC-1322-001, where beryllium is determined to be the bounding special reflector material. Special reflectors are defined in this report as beryllium, beryllium oxide, carbon (graphite), heavy water, magnesium oxide, and depleted uranium. The presence of all special reflectors is limited to a total quantity of 1 wt.% of the payload contents.

6.2.1 FGE Cases

Table 6.2-3 provides a description of each FGE content case. The FGE-1, FGE-2a, -2b, and -2c cases are general payloads applicable to canisters of ILW material where the ^{239}Pu fissile nuclides (or FGEs of other fissile nuclides), in any form or distribution, with or without ^{240}Pu, are contained in manually compacted wastes and the waste contains less than or equal to 1% of special reflectors by weight that is not chemically or mechanically bound to the waste.

Manual compaction represents the work force of an individual compressing waste materials into a content drum, whereas machine compacted represents the higher forces of a machine able to compress much more waste material into a content drum. Machine compaction is represented in the criticality models by a larger volume fraction of polyethylene materials in the waste content, defined by the FGE-5 case.

Materials that can credibly provide better than 15% polyethylene/85% water equivalent reflection are termed “special reflectors” and are not authorized for shipment under FGE-1, FGE-2a, -2b, and -2c cases in quantities that exceed 1% by weight. The FGE-3 case represents an allowable increase in special reflector materials that are not chemically or mechanically

bound to the waste materials, and thus may be distributed throughout the moderator (i.e., mixed with fissile material) and the reflector region (i.e., surrounding the fissile matrix). The FGE-4 case represents an allowable increase in special reflector materials that are chemically or mechanically bound to the waste materials, and thus may be distributed throughout the moderator (i.e., mixed with fissile material) and are not available within the reflector region.

6.2.2 FEM Cases

Table 6.2-4 describes each FEM content case. The low-enriched uranium (LEU) contents are restricted to material that is primarily uranium (in terms of the heavy metal component) and waste matrix material is distributed within a canister in such a manner that the maximum enrichment of the uranium does not exceed the defined wt.% ^{235}U in any location of the waste material, and there are no variations in the fissile concentration that exceed 0.96% ^{235}U FEM in any location.

The FEM-1 case applies to a mixture with debris (e.g., particle/lump) size characteristic dimensions (i.e., diameter or thickness) that are determined to be subcritical under the USL. For waste mixtures of unlimited debris size characteristic dimensions, the FEM-2 case determines a reduced ^{235}U enrichment level such that all debris dimensions are subcritical under the USL. The debris is evaluated as rods and spherical particles to cover ILW and fuel waste contents. A homogeneous fissile volume configuration is evaluated to ensure the limiting configuration is modeled.

Table 6.2-1 Fissile Gram Equivalent Waste Content Cases

Waste Contents		Fissile Gram Equivalent Cases	Fissile Gram Equivalent $g^{239}Pu$ Limits
Manually compacted with ≤1% by weight Be		FGE-1	335
Manually compacted with ≤1% by weight Be with minimum $g^{240}Pu$ credit	≥ 5 $g^{240}Pu$	FGE-2a	350
	≥ 15 $g^{240}Pu$	FGE-2b	370
	≥ 25 $g^{240}Pu$	FGE-2c	390
Manually compacted with >1% by weight Be (not chemically or mechanically bound)		FGE-3	121
Manually compacted with >1% by weight Be (chemically or mechanically bound)		FGE-4	320
Machine compacted with ≤1% by weight Be		FGE-5	245

Table 6.2-2 Fissile Equivalent Mass Waste Content Cases

Contents		Fissile Equivalent Mass Cases	^{235}U Weight Percent Limits
Manually compacted waste with a particle size characteristic dimensional restriction that is primarily uranium (in terms of the heavy metal component) with waste matrix distributed to not exceed enrichment limit	Manually compacted with ≤1% by weight Be, 15% polyethylene moderator	FEM-1	0.96 wt.% particles: ≤0.05cm and/or ≥4.0cm (radially)
Manually compacted waste without a particle size limit that is primarily uranium (in terms of the heavy metal component) with waste matrix distributed to not exceed enrichment limit	Manually compacted with ≤1% by weight Be, 15% polyethylene moderator	FEM-2	0.80 wt.%

Table 6.2-3 Fissile Gram Equivalent Waste Content Case Description

Content Code	Fissile Material ($g^{240}Pu$)	Special Reflector (chemically or mechanically bound?)	Method of Compacting	Moderator	Reflector
FGE-1	^{239}Pu	Be ≤ 1 wt.% (No)	Manual	CH_2 - 15% Water - 84% Be - 1%	CH_2 - 15% Water - 84% Be - 1%
FGE-2 a, b, c	^{239}Pu + ^{240}Pu (5, 10, 15 g)	Be ≤ 1 wt.% (No)	Manual	CH_2 - 15% Water - 84% Be - 1%	CH_2 - 15% Water - 84% Be - 1%
FGE-3	^{239}Pu	Be > 1 wt.% (No)	Manual	CH_2 - 15% Water - 84% Be - 1-80%	Be - 100%
FGE-4	^{239}Pu	Be > 1 wt.% (Yes)	Manual	CH_2 - 15% Water - 84% Be - 1-80%	CH_2 - 15% Water - 84% Be - 1%
FGE-5	^{239}Pu	Be ≤ 1 wt.% (No)	Machine	CH_2 - 100%	CH_2 - 99% Be - 1%

Table 6.2-4 Fissile Equivalent Mass Waste Content Case Description

Content Code	Fissile Material	Special Reflector (chemically or mechanically bound?)	Method of Compacting	Moderator	Reflector
FEM-1	^{235}U 0.96 wt.% limited debris size	Be ≤ 1 wt.% (No)	Manual	CH_2 - 15% Water - 84% Be - 1%	CH_2 - 15% Water - 84% Be - 1%
FEM-2	^{235}U 0.80 wt.% unlimited debris size	Be ≤ 1 wt.% (No)	Manual	CH_2 - 15% Water - 84% Be - 1%	CH_2 - 15% Water - 84% Be - 1%

6.3 General Considerations

6.3.1 Model Configuration

The criticality safety model for the package is based on the dimensions provided in the package licensing drawings. Using the drawings, the dimensions as modeled are listed in Table 6.3-1 with the model shown in Figure 6.3-1.

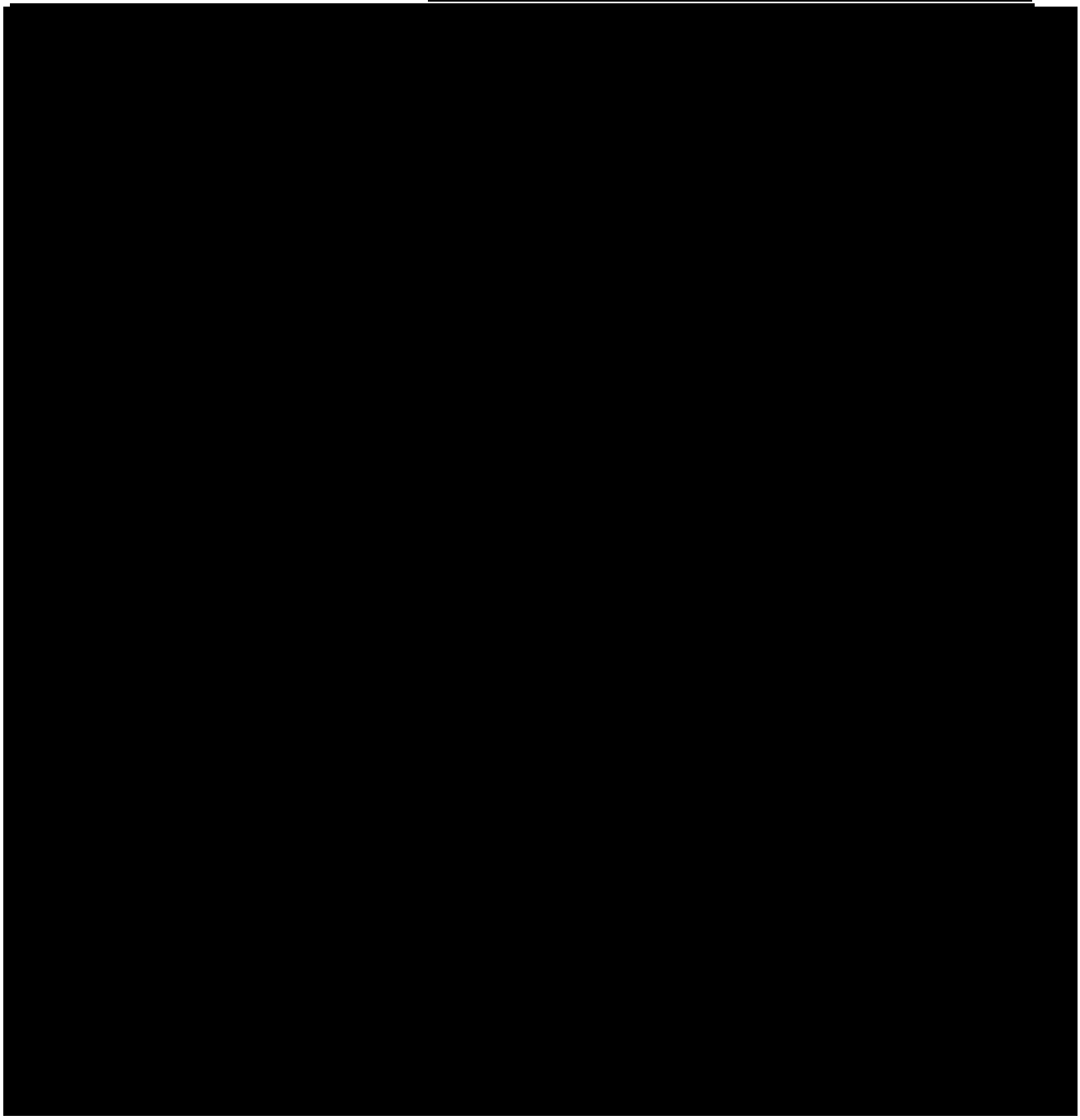


Table 6.3-1 Primary MCNP Model Package Dimensions

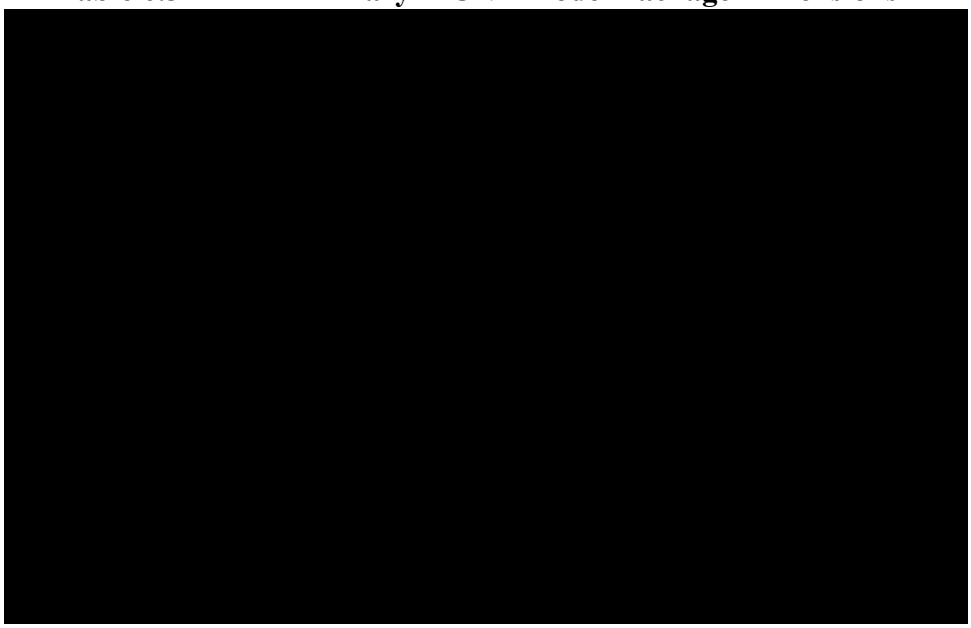


Figure 6.3-1 [redacted] Criticality Model – Package Geometry

Figure 6.3-2 Baseline Package Array Model

Figure 6.3-3 Single Package Model

6.3.2 Material Properties

The packaging materials defined for the MCNP models are DCI and [redacted] The fissile content is Pu metal and U metal and are considered to bound other plutonium and uranium compounds, respectively, based on density and absorption. Thus, all Pu and U compounds are acceptable as contents under the FGE and FEM limits, respectively. The moderator and reflector may be a combination of light water, polyethylene and Be dependent on case. The compositions and densities of these materials are summarized below.

[redacted]

Material properties for stainless steel [redacted]

Material properties for [redacted] are presented in Table 6.3-3. The composition for ductile cast iron is given in Table 1 of [redacted] The methodology to determine the composition for nuclear analyses is the same as used in PNNL-15870 [6.6]: elements with a maximum value are set to their maximum: C and Si were set to the average of their ranges, which satisfies the C + 1/3 Si ≤ 4.5% criterion; and Fe was set to the remainder.

The S(α,β) thermal scattering cross section for Fe-56 is included for criticality calculations with [redacted]

Material properties for light water, polyethylene, beryllium, plutonium, and uranium are presented in Table 6.3-4. Light water includes the S(α,β) thermal scattering cross sections to ensure accurate results for criticality calculations [redacted] Polyethylene includes the proper S(α,β) thermal scattering cross sections to ensure accurate results for criticality calculations [redacted] Beryllium includes the proper S(α,β) thermal scattering cross sections to ensure accurate results for criticality calculations with [redacted]

Table 6.3-2 Nuclear Properties of [redacted] Stainless Steel

[redacted]

Table 6.3-3 Nuclear Properties of [redacted]

[redacted]

Table 6.3-4 Nuclear Properties of Materials

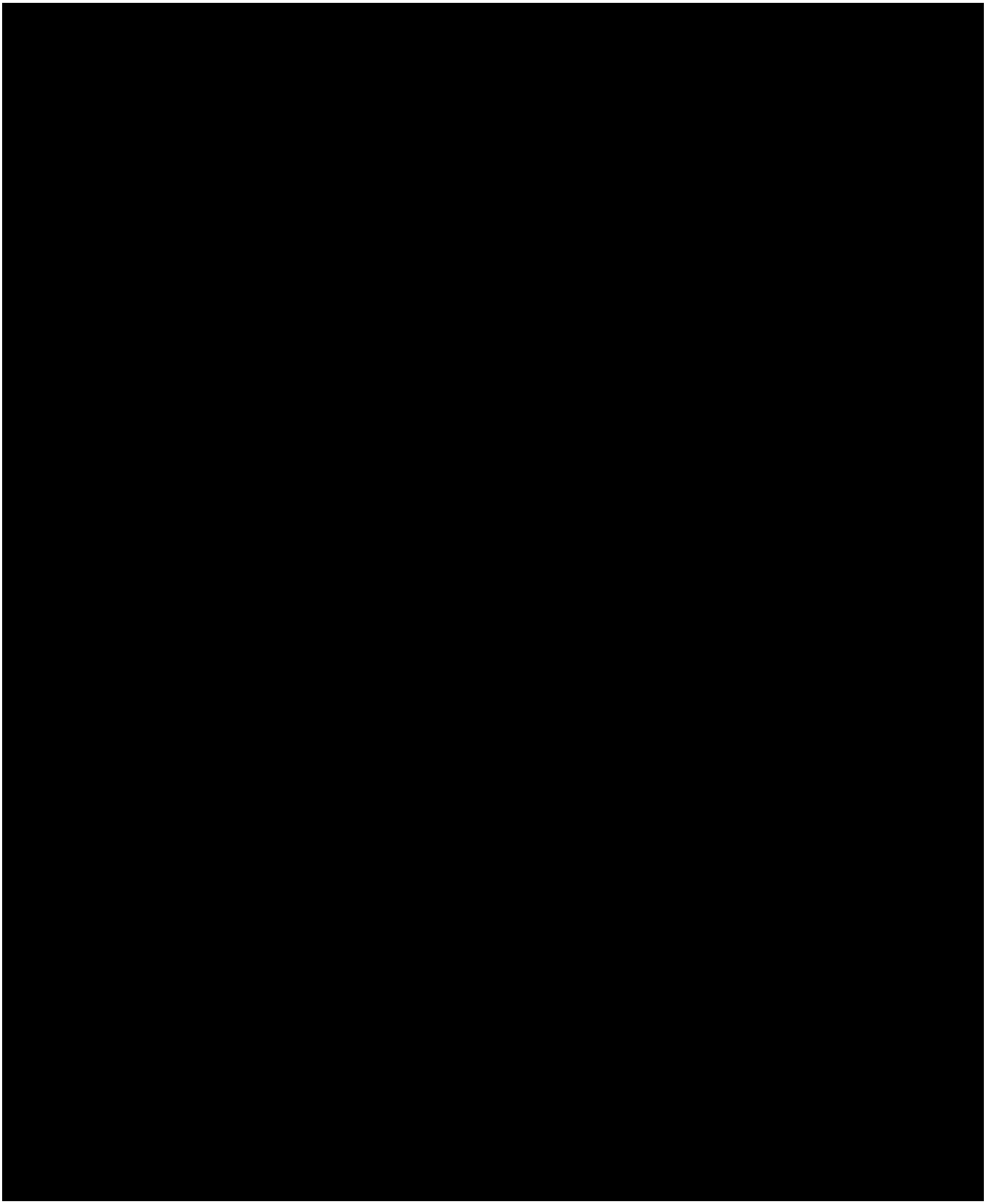
6.3.3 Computer Codes and Cross-Section Libraries

[redacted]

6.3.4 Demonstration of Maximum Reactivity

The criticality analysis varies the mass of fissile material to determine the maximum quantity for content cases while demonstrating compliance with 10 CFR 71.55 and 10 CFR 71.59 [1]. All content limits are evaluated to ensure subcriticality of $k_{eff} + 2\sigma$ below the respective upper subcritical limit (USL).

The single package model consists of the package with 20 in. (50.8 cm) of close, full-density water reflection on all sides. [redacted]



ratio of the critical mass limit for ^{239}Pu to that of the given isotope. So, the FGE conversion factor for isotope X is calculated based on the listed critical mass (m_X) of the isotope as:

$$FGE_x = \frac{m_{Pu-239}}{m_X}$$

The reference critical mass limits along with the location in the ANSI standard that they are pulled from and the resulting FGE conversion factors are provided in Table 6.3-6.

6.3.4.1 Fissile Gram Equivalent (FGE) Mass Limit Method

For the FGE single package and package array evaluations, four studies are performed. These studies are listed in the order they are examined.

6.3.4.1.1 Mass Determination - Base Study

The first study is referred to as the base study. This study determines the optimal H/^{239}Pu that results in the maximum mass of ^{239}Pu with $k_{eff} + 2\sigma$ less than the USL. This study models a homogeneous sphere of the fissile and moderating material in the CCV cavity, with the remainder of the CCV cavity filled with the reflector material. The OSV cavity and interspersed regions are modeled as void for this initial study. The H/^{239}Pu of the sphere is varied, thereby adjusting the size of the sphere, for five different ^{239}Pu mass levels to determine the optimally moderated H/^{239}Pu at the maximum ^{239}Pu mass with $k_{eff} + 2\sigma$ below the USL. For the FGE-3 and FGE-4 cases, the VF of Be in the fissile sphere is also a variable in determining the ^{239}Pu mass limit, as Be is not limited to ≤ 1 wt.%.

6.3.4.1.2 Fissile Sphere Position Study

The second study, the fissile sphere position study, verifies the bounding fissile sphere position inside the CCV. Three positions are examined: 1) the fissile sphere in the top corner of the CCV, 2) the fissile sphere in the top center of the CCV, and 3) the fissile sphere fully centered in the CCV, as shown in Figure 6.3-4. The off-center shifted fissile sphere positions represent where the most reflection is determined from scoping studies (i.e., by the thickest steel components, as steel has a higher density than iron); resultant values of k_{eff} are similar for both the single package and the package array, showing there is little to no interaction between packages, thus reflection has a larger contribution to k_{eff}. For the position of the fissile sphere in the top corner in the package array, the fissile sphere is placed in a radial position to be closest to the two neighboring packages in the array, as shown in Figure 6.3-5. Note that the sphere at the top of the CCV also means that the fissile sphere sees the largest possible reflection in the package due to the thickness of the CCV stainless steel lid.

6.3.4.1.3 Flooding Configuration

The flooding configuration study is performed for the single package and HAC package array evaluations. For the single package evaluation, flooding in the OSV cavity (Region 1 in Figure 6.3-6) is examined. In this study, the VF of the water in the OSV cavity region is varied from 0.0 to 1.0, while the VF of the water outside of the package (Region 2 in Figure 6.3-6) is constant at 1.0. For each content case, the bounding flooding configuration from this study is applied to the remainder of the studies.

For the HAC package array, three configurations are studied. The VF of the water in the OSV cavity (Region 1 in Figure 6.3-6) is varied, the interspersed region (Region 2 in Figure 6.3-6) is varied, and both regions are varied simultaneously. The VFs were varied from 0.0001 to 1.0. For each content case, the bounding flooding configuration from this study is applied to the remainder of the studies.

6.3.4.1.4 Flooded H/Pu Iteration

If a flooding configuration is more reactive than what was analyzed in the base study (a dry package), a flooded H/Pu iteration study is performed to determine if the more reactive flooding configuration results in a different optimally moderated H/^{239}Pu. For this study, the mass limit determined in the base study is held constant as the H/^{239}Pu is varied with the bounding flooding configuration, generating a new H/^{239}Pu curve. If the new curve peaks at a different H/^{239}Pu value, the new H/^{239}Pu value is applied in the sensitivity studies. If this study did not result in a new, more reactive H/^{239}Pu value, the study is not included.

6.3.4.1.5 Sensitivity Studies

For each of the FGE cases, specific sensitivity studies relating to the unique features of the case are performed to determine the effect on the mass limit.

FGE-1 Be Removal

Two sensitivity studies for FGE-1 examine the effect of (1) removing the Be from the moderator and replacing it with water and (2) removing the Be from the moderator and reflector and replacing it with water. This study verifies that the inclusion of Be as the bounding special reflector increases reactivity when compared to the CH_2 - water moderator. The conclusions of the FGE-1 sensitivity studies are applied to the FGE-2a, FGE-2b, and FGE-2c cases.

FGE-3 Be Reflector VF Reduction

This study examines the effect on reactivity of the FGE-3 cases from reducing the overall VF of the Be reflector surrounding the fissile sphere from 100% VF to 1% VF.

FGE-5 Reflector VF Reduction

This sensitivity study determines the effect on reactivity of reducing the VF of the FGE-5 reflector material (CH_2 - 99%, Be - 1%). The mass limit for FGE-5 is determined with full VF FGE-5 reflector material. This study determines if the reflection provided by the FGE-5 reflector material results in higher reactivity than reducing the reflection and allowing for more neutrons to communicate with other packages in an array.

6.3.4.2 Fissile Equivalent Mass (FEM) Enrichment Limit Method

For the FEM single package and package array evaluations, a homogeneous configuration and multiple heterogeneous fissile configurations are evaluated. For both single package and package array configurations, the ^{235}U enrichment limits are determined based on a limited debris size and an unlimited debris size. The initial maximum enrichment of 0.96 wt.% ^{235}U is based on ANSI/ANS-8.1, the subcritical enrichment limit for uranium particles mixed homogeneously with water with no limitations on mass or concentration [6.13]. The initial maximum enrichment sets a range of acceptable debris size limits that are subcritical below the USL. The enrichment is then reduced to determine when an unlimited debris size range is subcritical below the USL.

The flooding configuration study, as described in Section 6.3.4.1.3, is also evaluated for the FEM cases for the HAC package array configuration. For all cases, if the maximum resultant fissile material configuration does not fill the CCV cavity, then the configuration is shifted within the CCV to evaluate the effect.

6.3.4.2.1 Homogeneous Fissile Volume Case Study

The homogeneous fissile volume study evaluates varying H/^{235}U up to the U content mass limit and defined ^{235}U enrichment of 0.96 wt.% ^{235}U. This study determines the optimal H/^{235}U and U mass that results in $k_{eff} + 2\sigma$ less than the USL. A homogeneous cylinder of the fissile U-metal and moderating material is modeled in the CCV cavity, with any remainder of the CCV cavity filled with the reflector material equivalent to the moderator. The cylinder radius was held constant equal to the CCV cavity and the height was varied, thereby adjusting the total U mass content (not to exceed the U mass limit) and H/^{235}U (see Figure 6.3-7). The OSV cavity and interspersed regions are modeled as void, as this study is the base study for the HAC package array.

6.3.4.2.2 Heterogeneous Fissile Case Study

[redacted]

[redacted]

Table 6.3-5 Heterogeneous Fissile Content Model Parameters

Table 6.3-6 - FGE Conversion Factors

Isotope	ANSI Limit (kg)	FGE Conversion [1]	Reference	
			ANSI/ANS Standard	Location
Pu-239	0.45	1.000E+00	8.1	§5.2
U-233	0.5	9.000E-01		
U-235	0.7	6.429E-01		
Pu-236	0.6	7.500E-01	8.15	Table 2
Pu-238	5.1	8.824E-02		Table 1
Pu-241	0.185	2.432E+00		Table 2
Pu-242	55	8.182E-03		Table 1
U-232	1	4.500E-01		Table 1
U-234	59	7.627E-03		Table 1
Np-237	35	1.286E-02		Table 1
Am-241	24	1.875E-02		Table 1
Am-242m	0.011	4.091E+01		Table 2
Am-243	65	6.923E-03		Table 1
Cm-242	6	7.500E-02		Table 1
Cm-243	0.09	5.000E+00		Table 2
Cm-244	11	4.091E-02		Table 1
Cm-245	0.023	1.957E+01		Table 2
Cm-246	16	2.813E-02		Table 1
Cm-247	0.5	9.000E-01		Table 2
Cf-249	0.01	4.500E+01		Table 2
Cf-251	0.005	9.000E+01		Table 2

Note: [1] For any non-uranium or non-plutonium isotopes, if there are multiple isotopes of the same element present in the contents, the highest conversion factor for the given element should be used.

Figure 6.3-4 FGE Fissile Sphere Positions

Figure 6.3-5 FGE Fissile Sphere Positioning for Package Arrays

Figure 6.3-6 Floodable Regions:

Figure 6.3-7 FEM Fissile Homogeneous Cases

Figure 6.3-8 FEM Fissile Heterogeneous Cylinder Cases

Figure 6.3-9 FEM Fissile Heterogeneous Sphere Cases

This page intentionally left blank.

6.4 Single Package Evaluation

6.4.1 FGE Single Package Configuration

One model is considered for the single package evaluation that is representative of both NCT and HAC, as there is no damage to the package considered. Because the single package evaluation must consider the most reactive inleakage of water, and there is no package damage considered, one model is sufficient for the single package evaluation. The single package has close full-water reflection of 20.0 in. (50.8 cm).

6.4.2 FGE Single Package Summary Results

See Table 6.4-1 for the summary of the most reactive, single package FGE cases. Detailed results are summarized below for the FGE-1 case. Only the most reactive case is summarized for the remaining FGE configurations.

6.4.2.1 FGE-1 Single Package

FGE-1 simulates non-machine compacted waste that contains less than or equal to 1% Be special reflector. The moderator consists of 15% polyethylene, 84% light water, and 1% Be by volume. The reflector is identical to the moderator.

6.4.2.1.1 FGE-1 Single Package Baseline

As shown in Table 6.4-2 and Figure 6.4-1, a mass of 335 g of ^{239}Pu at H/^{239}Pu of 900 results in the bounding configuration under the USL of 0.93930, with a $k_{eff} + 2\sigma$ of 0.93341.

6.4.2.1.2 FGE-1 Fissile Sphere Positioning

This study shows that the fissile position selected in the baseline study is the bounding position. In the baseline study, the fissile sphere is modeled in the top corner. For this study, the sphere is also modeled centered at the top of the cavity and centered in the cavity. The mass of ^{239}Pu and H/^{239}Pu are held constant at the baseline configuration values: 335 g^{239}Pu and H/^{239}Pu of 900. As shown in Table 6.4-3, modeling the fissile sphere in the top corner is the bounding position for the FGE-1 single package configuration.

6.4.2.1.3 FGE-1 Flooding Configuration

As the single package evaluation considers close full-water reflection, this study only examines the sensitivity of the FGE-1 case to OSV cavity flooding. In examining this flooding scenario, this study is verifying that the ductile iron and steel of the OSV and CCV, respectively, are better reflectors than water. As shown in Table 6.4-4, 0.01 VF flooding in the OSV cavity is the bounding flooding, with $k_{eff} + 2\sigma$ of 0.93474.

6.4.2.1.4 FGE-1 Be Sensitivity

This study shows that the Be special reflector in both the moderator and reflector serves to increase reactivity over having a pure 15%/85% polyethylene/water moderator and reflector. As shown in Table 6.4-5 and Figure 6.4-2, removing the Be from the moderator results in a statistically significant decrease in reactivity (0.93474 vs. 0.93342). Similarly, removing the Be from the system entirely results in a statistically significant decrease in reactivity (0.93474 vs. 0.93279). Therefore, the inclusion of 1% Be by bounds a pure 15%/85% polyethylene/water moderator and reflector. This conclusion is applied to the FGE-2a, -2b, and -2c cases, and as such is not analyzed for those cases.

Table 6.4-1 Mass Limit for FGE Cases - Single Package

[redacted]

Table 6.4-2 FGE-1 Baseline Configuration – Single Package

[redacted]

Table 6.4-3 FGE-1 Fissile Sphere Position – Single Package

[redacted]

Table 6.4-4 FGE-1 Flooding Configuration– Single Package

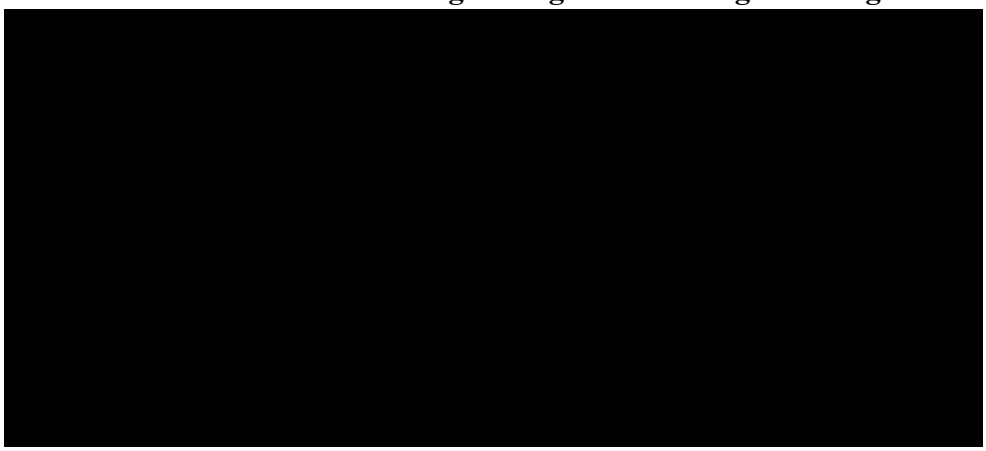


Table 6.4-5 FGE-1 Effect of Be Removal from Moderator and Reflector– Single Package

Figure 6.4-1 Effect of H/^{239}Pu on k_{eff} for Several ^{239}Pu masses – FGE-1 Single Package

Figure 6.4-2 Effect of Be Removal on k_{eff} – FGE-1 Single Package

6.4.2.2 FGE-2a Single Package

FGE-2a credits 5 g of ^{240}Pu in its analysis but is otherwise identical to FGE-1. The moderator consists of 15% polyethylene, 84% light water, and 1% Be by volume and the reflector is identical to the moderator.

The most reactive configuration for the FGE-2a single package is 350 g^{239}Pu at H/^{239}Pu of 900 and with 0.001 VF flooding in the OSV cavity, with $k_{eff} + 2\sigma$ of 0.93718, below the USL of 0.9393.

6.4.2.3 FGE-2b Single Package

FGE-2b credits 15 g of ^{240}Pu in its analysis but is otherwise identical to FGE-1. The moderator consists of 15% polyethylene, 84% light water, and 1% Be by volume and the reflector is identical to the moderator.

The most reactive configuration for the FGE-2b single package is 370 g^{239}Pu at H/^{239}Pu of 900 and with 0.01 VF flooding in the OSV cavity, with $k_{eff} + 2\sigma$ of 0.93501, below the USL of 0.9393.

6.4.2.4 FGE-2c Single Package

FGE-2c credits 25 g of ^{240}Pu in its analysis but is otherwise identical to FGE-1. The moderator consists of 15% polyethylene, 84% light water, and 1% Be by volume and the reflector is identical to the moderator.

The most reactive configuration for the FGE-2c single package is 390 g^{239}Pu at H/^{239}Pu of 1000 and with 0.1 VF flooding in the OSV cavity, with $k_{eff} + 2\sigma$ of 0.93563, below the USL of 0.9393.

6.4.2.5 FGE-3 Single Package

FGE-3 simulates non-machine compacted waste that is not chemically or mechanically bound to the special reflector material. The moderator consists of a 15%-to-84% ratio of polyethylene to light water, and a minimum of 1% Be by volume. The Be of the moderator is varied from 1% to 80% to determine its effects on reactivity. The reflector consists of 100% Be.

The most reactive configuration for the FGE-3 single package is 0.01 Be volume fraction, 121 $g^{239}Pu$, $H/^{239}Pu$ of 800, a full density Be reflector, and 0.5 VF flooding in the OSV cavity, with $k_{eff} + 2\sigma$ of 0.93534, below the USL of 0.9368.

6.4.2.6 FGE-4 Single Package

FGE-4 simulates non-machine compacted waste that is chemically or mechanically bound to the special reflector material. The moderator consists of a 15%-to-84% ratio of polyethylene to light water, and a minimum of 1% Be by volume. The Be of the moderator is varied from 1% to 80% to determine its effects on reactivity. The reflector is fixed at 15% polyethylene, 84% water, and 1% Be.

The most reactive configuration for the FGE-4 single package is 0.4 Be volume fraction, 320 $g^{239}Pu$, $H/^{239}Pu$ of 900, and 0.1 VF flooding in the OSV cavity, with $k_{eff} + 2\sigma$ of 0.93237, below the USL of 0.9368.

6.4.2.7 FGE-5 Single Package

FGE-5 simulates machine compacted waste. The moderator consists of 100% polyethylene. The reflector consists of 99% polyethylene and 1% Be.

The most reactive configuration for the FGE-5 single package is 245 $g^{239}Pu$ with $H/^{239}Pu$ of 900 and 0.0 VF flooding in the OSV cavity, with $k_{eff} + 2\sigma$ of 0.93308, below the USL of 0.9368.

6.4.3 FEM Single Package Configuration

One model is considered for the single package evaluation that is representative of both NCT and HAC. Because the single package evaluation must consider the most reactive inleakage of water, and there is no package damage considered, one model is sufficient for the single package evaluation. The single package has close full-water reflection of 20.0 in. (50.8 cm). The HAC package array fissile particle and pitch configuration results, for FEM-1 cases, showed that above a particle radius of 3 cm, the $k_{eff} + 2\sigma$ is always below the USL of 0.9414. Therefore, the single package cases are evaluated for a reduced set of particle-to-pitch configurations.

FEM-1 and FEM-2 simulate non-machine compacted waste that contains less than or equal to 1% Be special reflector. The moderator consists of 15% polyethylene, 84% light water, and 1%

Be by volume. The FEM-1 cases evaluate spherical and cylindrical particle configurations at 0.96wt.% ^{235}U to determine the particle size restriction. The FEM-2 cases evaluate spherical and cylindrical particle configurations at 0.80wt.% ^{235}U to ensure there is no particle size restriction. Both cases evaluate a square and hexagonal array of particles at varying pitches.

6.4.4 FEM Single Package Summary Results

See Table 6.4-6 for the summary of the most reactive, single package FEM cases.

6.4.4.1 FEM-1 Single Package Baseline

FEM-1 cases represent 0.96 wt.% ^{235}U and define the particle size restriction. The peak $k_{eff} + 2\sigma$ for each of the fissile OR and half-pitch configurations are shown in Table 6.4-3 for the spherical particle configuration and Table 6.4-4 for the cylindrical particle configuration. Figure 6.4-5 depicts the trend lines of all sphere, hexagonal array data, and Figure 6.4-5 for the cylindrical, hexagonal array data, as the hexagonal configuration was typically more reactive due to the increase in moderation in the array.

The FEM-1, spherical particle results show that a particle size of ≤0.1cm and/or ≥3.0cm is subcritical below the USL of 0.9414. The FEM-1, cylinder particle results show that a particle size of ≤0.05cm and/or ≥2.0cm is subcritical below the USL of 0.9414. However, based on HAC package array results, the FEM-1 particle size limit is defined by the outermost bounds and must be ≤0.05cm and/or ≥4.0cm radially.

Therefore, the particle sizes greater than the USL (highlighted in purple in the tables) are evaluated at a lower ^{235}U enrichment, as FEM-2 cases, to define an unlimited particle size case. The most reactive FEM-1 single package case has $k_{eff} + 2\sigma$ of 0.93559 (highlighted gray in Table 6.4-7).

6.4.4.2 FEM-2 Single Package Baseline

FEM-2 cases represent 0.80 wt.% ^{235}U with unlimited particle sizes. The peak $k_{eff} + 2\sigma$ for each of the fissile OR and half-pitch configurations are shown in Table 6.4-9 for the sphere particle configuration and Table 6.4-10 for the cylinder particle configuration. Figure 6.4-5 compares FEM-1 and 2 cases for cylinder, hexagonal array at the limited particle sizes. The comparison displays the reduced enrichment decreases $k_{eff} + 2\sigma$ sufficiently below the USL for the unlimited particle size, FEM-2 case.

The FEM-2, sphere and cylinder particle results show that unlimited particle sizes are subcritical below the USL of 0.9414. The most reactive FEM-2, single package has a $k_{eff} + 2\sigma$ of 0.93317.

6.4.4.3 FEM-1 Homogeneous Volume Single Package Configuration

The homogeneous volume configuration is described in Section 6.3.4.2.1. The homogeneous fissile volume study evaluates the varying H/^{235}U up to the U content mass limit and 0.96 wt.% ^{235}U enrichment.

The most reactive FEM-1 homogeneous volume configuration, single package case, as shown in Table 6.4-6, has $k_{eff} + 2\sigma$ of 0.91183. However, this result is less than the bounding FEM-1 case, with $k_{eff} + 2\sigma$ of 0.93559 (Table 6.4-7), and thus not the most reactive FEM-1, single package case configuration.

Table 6.4-6 Limits for FEM Cases - Single Package

[redacted]

Table 6.4-7 - FEM-1, Sphere Particle Baseline Configuration – Single Package

[redacted]

Table 6.4-8 FEM-1, Cylinder Particle Baseline Configuration – Single Package

[redacted]

Table 6.4-9 FEM-2, Sphere Particle Baseline Configuration - Single Package

[redacted]

Table 6.4-10 FEM-2, Cylinder Particle Baseline Configuration - Single Package

[redacted]

Table 6.4-11 FEM-2, Homogeneous Fissile Volume Configuration - Single Package

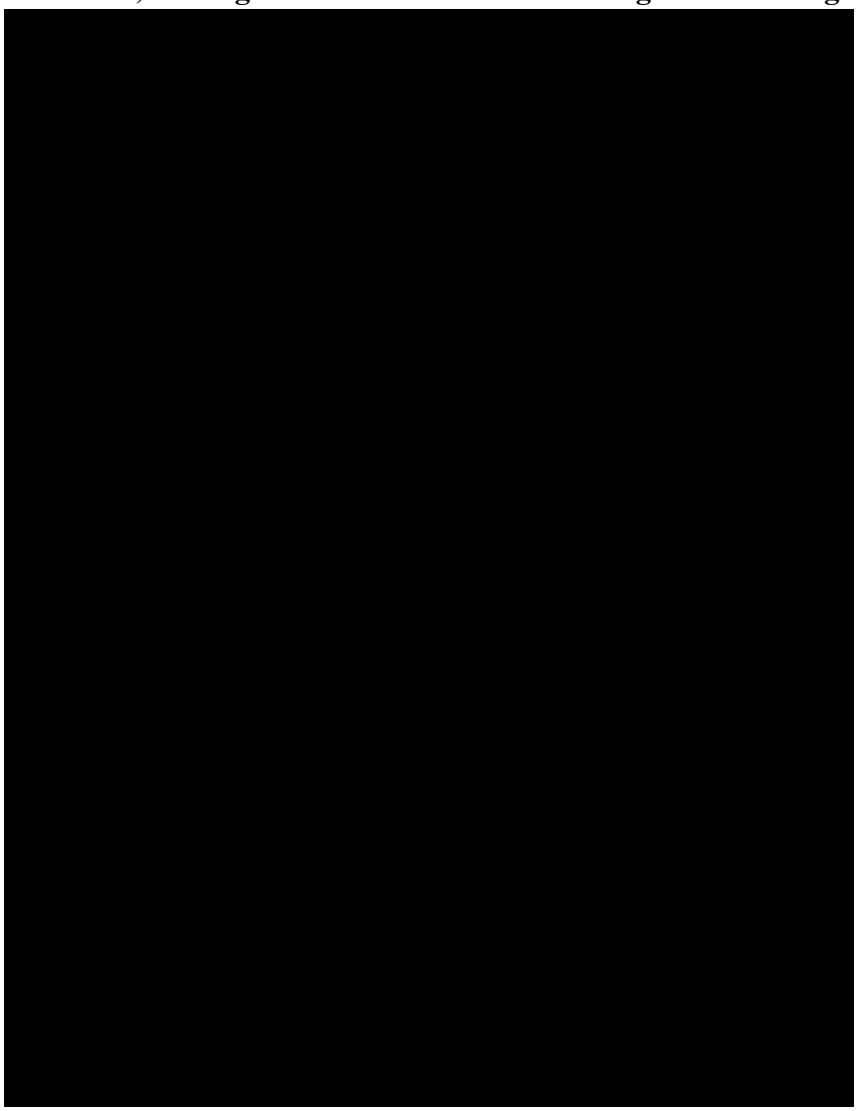


Figure 6.4-3 FEM-1, Sphere Particle, Hex Array – Single Package

Figure 6.4-4 FEM-1, Cylinder Particle, Hex Array - Single Package

Figure 6.4-5 FEM-1 and 2, Cylinder Particle, Hex Array Comparison - Single Package

6.5 Evaluation of Package Arrays Under Normal Conditions of Transport

As the package has a CSI of 0.0, and the arrays analyzed are infinitely large, only the HAC array is analyzed. In the HAC package array, the baseline study varying H/^{239}Pu to determine the ^{239}Pu mass limits models a package devoid of flooding. The flooding is then analyzed in subsequent sensitivity studies. Thus, the HAC array analysis is bounding of an NCT array analysis.

This page intentionally left blank.

6.6 Package Arrays Under Hypothetical Accident Conditions

6.6.1 FGE HAC Package Array Configuration

For the initial package array evaluation, all floodable spaces are modeled as void. Once the bounding moderator/reflector combination is determined for an FGE case, a study is performed to determine the bounding flooding.

6.6.2 FGE HAC Package Array Results

See Table 6.6-1 for the summary of the most reactive FGE cases in the HAC package array evaluation. Detailed results are summarized below for the FGE-1 case. Only the most reactive case is summarized for the remaining FGE configurations.

6.6.2.1 FGE-1 HAC Package Array

FGE-1 simulates non-machine compacted waste that contains less than or equal to 1% Be special reflector. The moderator consists of 15% polyethylene, 84% light water, and 1% Be by volume. The reflector is identical to the moderator.

6.6.2.1.1 FGE-1 HAC Package Array Baseline

As shown in Table 6.6-2 and Figure 6.6-1, a mass of 335 g^{239}Pu at H/^{239}Pu of 800 results in the bounding configuration under the USL of 0.93930 with a $k_{eff} + 2\sigma$ of 0.93562.

6.6.2.1.2 FGE-1 Fissile Sphere Positioning

This study shows that the fissile position selected in the baseline study is the bounding position. In the baseline study, the fissile sphere is modeled in the top corner. For this study, the sphere is also modeled centered at the top of the cavity and centered in the cavity. The mass of ^{239}Pu and H/^{239}Pu are held constant at the baseline case values: 335 g^{239}Pu and H/^{239}Pu of 800. As shown in Table 6.6-3, modeling the fissile sphere in the top corner is the bounding position for the FGE-1 HAC package array configuration. This conclusion is applied to the FGE-2a, -2b, and -2c HAC package array configurations, and as such is not analyzed for those cases.

6.6.2.1.3 FGE-1 Flooding Configuration

This study examines the sensitivity of the FGE-1 case to three flooding scenarios: flooding in only the OSV cavity, interspersed moderation, and flooding in both the OSV cavity and interspersed simultaneously. In examining these flooding scenarios, this study is verifying that the ductile iron and steel of the OSV and CCV, respectively, are better reflectors than water. As shown in Table 6.6-4, 0.001 VF flooding in the OSV cavity has the largest increase in reactivity

over void, with k_{eff} + 2σ of 0.93593. Because there is a flooding configuration more reactive than the baseline configuration, a flooding iteration study is performed to see if the flooding affects the baseline configuration.

6.6.2.1.4 FGE-1 Flooding Iteration

This study takes the flooding configuration with the largest k_{eff} and generates a new H/^{239}Pu curve, as in the baseline study, to determine if the flooding affects the optimum H/^{239}Pu. As shown in Table 6.6-5 and Figure 6.6-2, this flooding configuration results in a more reactive H/^{239}Pu for FGE-1, with H/^{239}Pu of 900 as the bounding H/^{239}Pu.

6.6.2.1.5 FGE-1 Be Sensitivity

This study shows that the Be special reflector in both the moderator and reflector serves to increase reactivity over having a pure 15%/85% polyethylene/water moderator and reflector. As shown in Table 6.6-6 and Figure 6.6-3, removing the Be from the moderator results in a statistically significant increase in reactivity (0.93669 vs. 0.93603). Also, removing the Be from the system entirely results in a statistically significant decrease in reactivity (0.93669 vs. 0.93495). Therefore, the inclusion of 1% Be by volume increases the reactivity of the system and is bounding of a pure water/polyethylene moderator mixture. Therefore, 335 g^{239}Pu at H/^{239}Pu of 900 and with 0.001 VF flooding in the OSV cavity is the most reactive baseline configuration for the FGE-1 HAC package array, with k_{eff} + 2σ of 0.93669, below the USL of 0.9393. This conclusion is applied to the FGE-2a, -2b, and -2c cases, and as such is not analyzed for those cases.

Table 6.6-1 Mass Limit Cases for FGE Cases - HAC Package Array

[redacted]

Table 6.6-2 FGE-1 Baseline Configuration - HAC Package Array

[redacted]

Table 6.6-3 FGE-1 Fissile Sphere Position – HAC Package Array

[redacted]

Table 6.6-4 FGE-1 Flooding Configuration– HAC Package Array

[redacted]

Table 6.6-5 FGE-1 Flooded H/Pu Iteration Effect on H/^{239}Pu– HAC Package Array

[redacted]

Table 6.6-6 FGE-1 Effect of Be Removal from Moderator and Reflector– HAC Package Array

[redacted]

Figure 6.6-1 Effect of H/^{239}Pu on k_{eff} for Several ^{239}Pu masses – FGE-1 HAC Package Array

Figure 6.6-2 Flooded H/Pu Iteration H/^{239}Pu Curve – FGE-1 HAC Package Array

Figure 6.6-3 Effect of Be Removal on k_{eff} – FGE-1 HAC Package Array

6.6.2.2 FGE-2a HAC Package Array

FGE-2a credits 5 g of ^{240}Pu in its analysis but is otherwise identical to FGE-1. The moderator consists of 15% polyethylene, 84% light water, and 1% Be by volume and the reflector is identical to the moderator.

The most reactive case of the FGE-2a HAC package array evaluation is the no flooding configuration, with a mass of 350 g of ^{239}Pu at H/^{239}Pu of 900, with $k_{eff} + 2\sigma$ of 0.93850, below the USL of 0.9393.

6.6.2.3 FGE-2b HAC Package Array

FGE-2b credits 15 g of ^{240}Pu in its analysis but is otherwise identical to FGE-1. The moderator consists of 15% polyethylene, 84% light water, and 1% Be by volume and the reflector is identical to the moderator.

The most reactive configuration for the FGE-2b HAC package array is 370 g^{239}Pu at H/^{239}Pu of 900 and with 0.0001 VF flooding in the OSV cavity, with $k_{eff} + 2\sigma$ of 0.93751, below the USL of 0.9393. FGE-2c HAC Package Array

FGE-2c credits 25 g of ^{240}Pu in its analysis but is otherwise identical to FGE-1. The moderator consists of 15% polyethylene, 84% light water, and 1% Be by volume and the reflector is identical to the moderator.

6.6.2.4 FGE-2c HAC Package Array

FGE-2c credits 25 g of ^{240}Pu in its analysis but is otherwise identical to FGE-1. The moderator consists of 15% polyethylene, 84% light water, and 1% Be by volume and the reflector is identical to the moderator.

The most reactive configuration for the FGE-2c HAC package array is 390 g^{239}Pu at H/^{239}Pu of 900 and with 0.001 VF flooding in the OSV, with $k_{eff} + 2\sigma$ of 0.93751, below the USL of 0.9393.

6.6.2.5 FGE-3 HAC Package Array

FGE-3 simulates non-machine compacted waste that is not chemically or mechanically bound to the special reflector material. The moderator consists of a 15%-to-84% ratio of polyethylene to light water, and a minimum of 1% Be by volume. The Be of the moderator is varied from 1% to 80% to determine its effects on reactivity. The reflector consists of 100% Be.

The most reactive configuration for the FGE-3 HAC package array is 121 g^{239}Pu at H/^{239}Pu of 800 and with 0.01 VF flooding in all regions, with $k_{eff} + 2\sigma$ of 0.93545, below the USL of 0.9368.

6.6.2.6 FGE-4 HAC Package Array

FGE-4 simulates non-machine compacted waste that is chemically or mechanically bound to the special reflector material. The moderator consists of a 15%-to-84% ratio of polyethylene to light water, and a minimum of 1% Be by volume. The Be of the moderator is varied from 1% to 80% to determine its effects on reactivity. The reflector is fixed at 15% polyethylene, 84% water, and 1% Be.

The most reactive configuration for the FGE-4 HAC package array is 320 $g^{239}Pu$ at $H/^{239}Pu$ of 900 and with 0.001 VF flooding in the OSV cavity, with $k_{eff} + 2\sigma$ of 0.93477, below the USL of 0.9368.

6.6.2.7 FGE-5 HAC Package Array

FGE-5 simulates machine compacted waste. The moderator consists of 100% polyethylene and the reflector consists of 99% polyethylene and 1% Be.

The most reactive configuration for the FGE-7 HAC package array is $245g^{239}Pu$ at $H/^{239}Pu$ of 900 with 0.01 VF flooding in all regions and a full-density cavity reflector, with $k_{eff} + 2\sigma$ of 0.93470, below the USL of 0.9393.

6.6.3 FEM HAC Package Array Configuration

For the initial package array evaluation, all floodable spaces are modeled as void. Once the bounding pitch and particle size combination is determined for a FEM case, a study is performed to determine the bounding flooding.

6.6.4 FEM HAC Package Array Summary Results

See Table 6.6-7 for the summary of the most reactive FEM cases. The FEM-1 spherical cases produce the largest particle size restriction and the FEM-1 cylindrical cases produce the smallest particle size restriction. Thus, the particle size limit is defined by the outermost bounds and must be ≤0.05cm and/or ≥4.0cm radially.

6.6.4.1 FEM-1 HAC Package Array Baseline

FEM-1 simulates non-machine compacted waste that contains less than or equal to 1% Be special reflector. The moderator consists of 15% polyethylene, 84% light water, and 1% Be by volume. The FEM-1 cases evaluate sphere and cylinder particle configurations at 0.96 wt.% ^{235}U to determine the particle size restriction. Square and hexagonal arrays of particles at varying pitches are evaluated for FEM-1.

The peak $k_{eff} + 2\sigma$ for each of the fissile outer radius (OR) and half-pitch configurations are shown in Table 6.6-8 for the spherical particle configuration and Table 6.6-9 for the cylindrical particle configuration. Figure 6.6-4 depicts the trend lines of all sphere, hexagonal array data, and Figure 6.6-5 for the cylinder, hexagonal array data, as the hexagonal configuration was typically more reactive due to the increase in moderation in the array.

The FEM-1, sphere particle results show that a particle size of ≤0.1cm and/or ≥4.0cm is subcritical below the USL of 0.9414. The FEM-1, cylinder particle results show that a particle size of ≤0.05cm and/or ≥2.0cm is subcritical below the USL of 0.9414. Thus, the FEM-1 particle size limit is defined by the outermost bounds and must be ≤0.05cm and/or ≥4.0cm radially.

Therefore, the particle sizes greater than the USL (highlighted in purple in the tables) are evaluated at a lower ^{235}U enrichment, as FEM-2 cases, to define an unlimited particle size case.

The most reactive FEM-1, HAC package array baseline case has a $k_{eff} + 2\sigma$ of 0.93320 (highlighted gray in the Table 6.6-9). This case represents the bounding configuration outside the particle limitation. Because the $k_{eff} + 2\sigma$ is near the USL, it is utilized in the flooding study to ensure the most reactive case is subcritical. Because other bounding fissile OR configurations outside the particle limitation are less than the most reactive case, often 0.04 or more below the USL of 0.9414, and the sensitivity of the system to increase in reactivity due to flooding is quite

small or statistically insignificant overall, flooding sensitivity studies are not performed for all bounding particle size configuration cases.

6.6.4.1.1 FEM-1 Flooding Configuration

The flooding cases evaluate the bounding FEM-1 case, (fissile OR = 2 cm, half-pitch = 3 cm). The flooding configurations are defined in Section 6.6.3 flooding of the OSV cavity, flooding of the interspersed region between packages, flooding of the OSV cavity and the interspersed region simultaneously. In examining these flooding scenarios, this study is verifying that the ductile iron and steel of the OSV and CCV, respectively, are better reflectors than water.

The bounding FEM-1, HAC package array flooding cases over the baseline case are highlighted gray in Table 6.6-13. Overall, the sensitivity of the system to an increase in reactivity due to flooding is quite small or statistically insignificant. The most reactive FEM-1, HAC package array case has a $k_{eff} + 2\sigma$ of 0.93345.

Table 6.6-7 Limits for FEM Cases - HAC Package Array

[redacted]

Table 6.6-8 FEM-1, Sphere Particle Baseline Configuration - HAC Package Array

[redacted]

Table 6.6-9 FEM-1, Cylinder Particle Baseline Configuration - HAC Package Array

[redacted]

Table 6.6-10 FEM-1, Cylinder Particle Flooding Configuration - HAC Package Array

[redacted]

Figure 6.6-4 FEM-1, Sphere Particle, Hex Array - HAC Package Array

Figure 6.6-5 FEM-1, Cylinder Particle, Hex Array - HAC Package Array

6.6.4.2 FEM-2 HAC Package Array Baseline

FEM-2 simulates non-machine compacted waste that contains less than or equal to 1% Be special reflector. The moderator consists of 15% polyethylene, 84% light water, and 1% Be by volume. The FEM-2 cases evaluate spherical and cylindrical particle configurations at 0.80 wt.% ^{235}U to ensure there is no particle size restriction. Square and hexagonal arrays of particles at varying pitches are evaluated for FEM-2.

The peak $k_{eff} + 2\sigma$ for each of the fissile OR and half-pitch configurations are shown in Table 6.6-11 for the spherical particle configuration and Table 6.6-12 for the cylindrical particle configuration. Figure 6.6-6 compares FEM-1 and 2 cases for cylinder, hexagonal array at the limited particle sizes. The comparison displays the reduced enrichment decreases $k_{eff} + 2\sigma$ sufficiently below the USL for the unlimited particle size, FEM-2 case.

The FEM-2, spherical and cylindrical particle results show that unlimited particle sizes are subcritical below the USL of 0.9414. The bounding configurations (highlighted gray in the tables) are utilized in the flooding study. The most reactive FEM-2, HAC package array baseline case has $k_{eff} + 2\sigma$ of 0.93883.

6.6.4.2.1 FEM-2 Flooding Configuration

The flooding cases evaluate the bounding FEM-2 spherical (fissile OR = 1 cm, half-pitch = 1.2 cm) and cylindrical (fissile OR = 0.5 cm, half-pitch = 0.9 cm) cases. The flooding configurations are defined in Section 6.6.3: flooding of the OSV cavity, flooding of the interspersed region between packages, and flooding of the OSV cavity and the interspersed region simultaneously. In examining these flooding scenarios, this study is verifying that the ductile iron and steel of the OSV and CCV, respectively, are better reflectors than water.

The bounding FEM-2, HAC package array flooding cases are highlighted gray in Table 6.6-13 for spherical particles and Table 6.6-14 for cylindrical particles. Overall, the sensitivity of the system to an increase in reactivity due to flooding is quite small or statistically insignificant. The flooding study does not result in an increase in $k_{eff} + 2\sigma$ for the most reactive FEM-2, HAC package array case, and thus remains the baseline case.

Table 6.6-11 FEM-2, Sphere Particle Baseline Configuration - HAC Package Array

[redacted]

Table 6.6-12 FEM-2, Cylinder Particle Baseline Configuration - HAC Package Array

[redacted]

Table 6.6-13 FEM-2, Sphere Particle Flooding Configuration - HAC Package Array

[redacted]

Table 6.6-14 FEM-2, Cylinder Particle Flooding Configuration - HAC Package Array

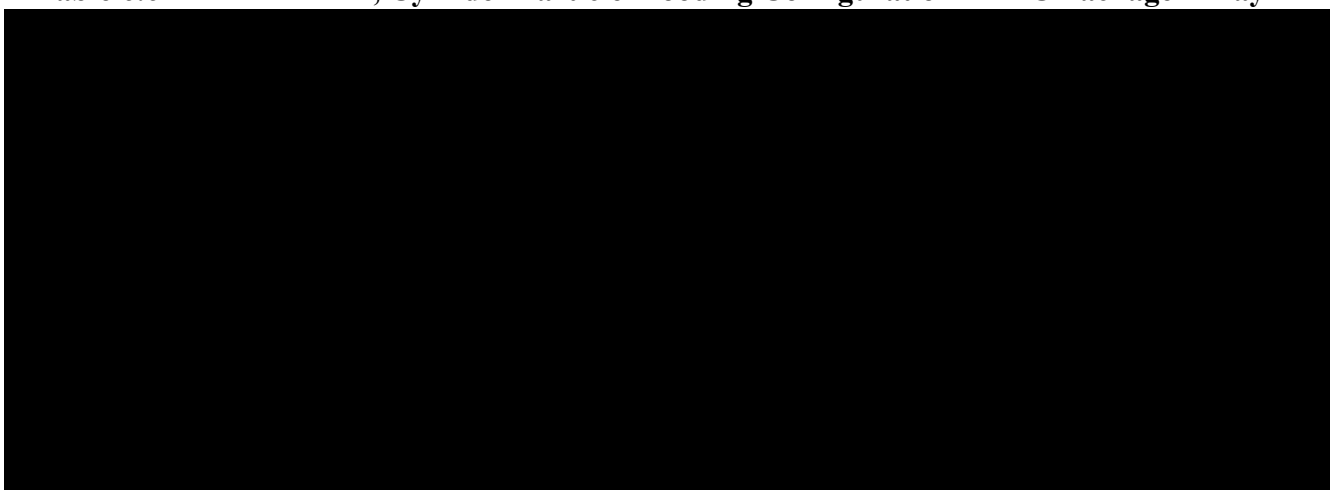


Figure 6.6-6 FEM-1 and 2, Cylinder Particle, Hex Array Comparison - HAC Package Array

6.6.4.3 FEM-1 Homogeneous Volume HAC Package Array Configuration

The homogeneous volume configuration is described in Section 6.3.4.2.1. The homogeneous fissile volume study evaluates the varying H/^{235}U up to the U content mass limit with a ^{235}U enrichment of 0.96 wt.%. Once the U mass limit is reached, only H/^{235}U is varied. The bounding configuration (highlighted gray in Table 6.6-36) is utilized in the flooding study.

6.6.4.3.1 FEM-1 Homogeneous Volume, Flooding Configuration

The flooding case evaluates the bounding FEM-1 homogeneous volume cases (H/^{235}U = 550 and H/^{235}U = 500), because they are statistically the same result. The flooding configurations are defined in Section 6.6.3: flooding of the OSV cavity, flooding of the interspersed region between packages, and flooding of the OSV cavity and the interspersed region simultaneously. In examining these flooding scenarios, this study is verifying that the ductile iron and steel of the OSV and CCV, respectively, are better reflectors than water.

The bounding FEM-1 homogeneous, HAC package array flooding cases over the baseline case are highlighted gray in Table 6.6-16. The table only shows the H/^{235}U of 500 results, as all cases were more reactive than H/^{235}U of 550. Overall, the sensitivity of the system to an increase in reactivity due to flooding is quite small or statistically insignificant.

The most reactive FEM-1 homogeneous volume configuration, HAC package array case has $k_{eff} + 2\sigma$ of 0.91824. However, this result is less than the bounding FEM-1 case, with a $k_{eff} + 2\sigma$ of 0.93345 (Table 6.6-10), and thus not the most reactive FEM-2, HAC package array case configuration.

Table 6.6-15 FEM-1, Homogeneous Fissile Volume Configuration - HAC Package Array

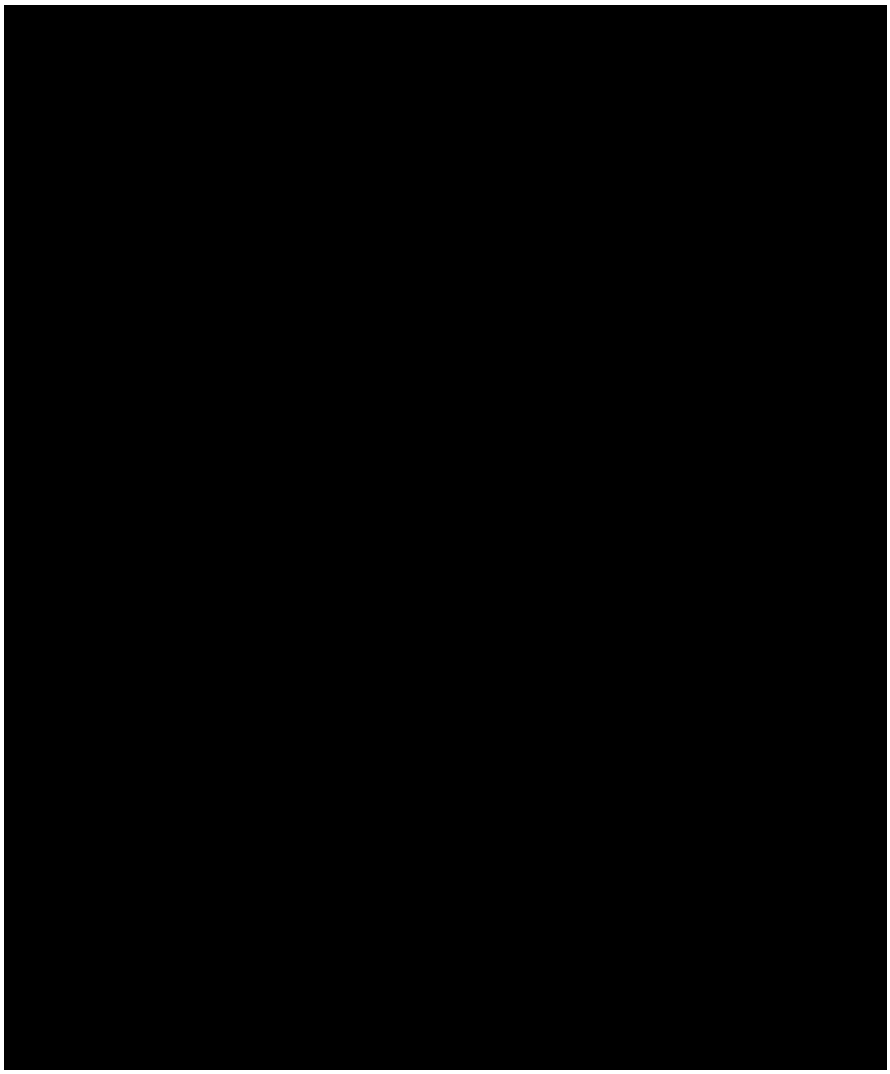


Table 6.6-16 FEM-1, Homogeneous Volume, Flooding Configuration - HAC Package Array

6.7 Fissile Material Packages for Air Transport

The package is not authorized for air transport.

This page intentionally left blank.

6.8 Benchmark Evaluation

The following benchmark evaluation was analyzed with identical code and cross section libraries to those used in the criticality safety calculations presented in this Chapter: [redacted]

6.8.1 Applicability of Benchmark Experiments

6.8.1.1 Plutonium Experiments

[redacted]

[redacted]

6.8.1.2 Low-Enriched Uranium Experiments

[redacted]

[redacted]

6.8.1.3 Area of Applicability

[redacted]

[redacted]

6.8.2 Bias Determination

[redacted]

6.8.2.1 Plutonium Solutions without Beryllium Reflector USL Function

6.8.2.2 Plutonium Solution with Beryllium Reflector USL Function

[redacted]

6.8.2.3 Low-Enriched Uranium System USL Function

[redacted]

Table 6.8-1 Criticality Safety Bias and USL Functions

[redacted]

Table 6.8-2 FEM Criticality Safety USL Functions

[redacted]

Table 6.8-3 Summary of Critical Benchmark Experiments – Plutonium Cases

[redacted]

Table 6.8-4 Summary of Critical Benchmark Experiments – Low-Enriched Uranium Cases

[redacted]

Table 6.8-5 Plutonium Critical Experiment Area of Applicability

[redacted]

Table 6.8-6 Low-Enriched Uranium Critical Experiment Area of Applicability

[redacted]

Table 6.8-7 USL Functions for Plutonium without Beryllium Reflector Critical Solution Benchmarks

[redacted]

Table 6.8-8 USL Functions for Plutonium with Beryllium Reflector Critical Solution Benchmarks

[redacted]

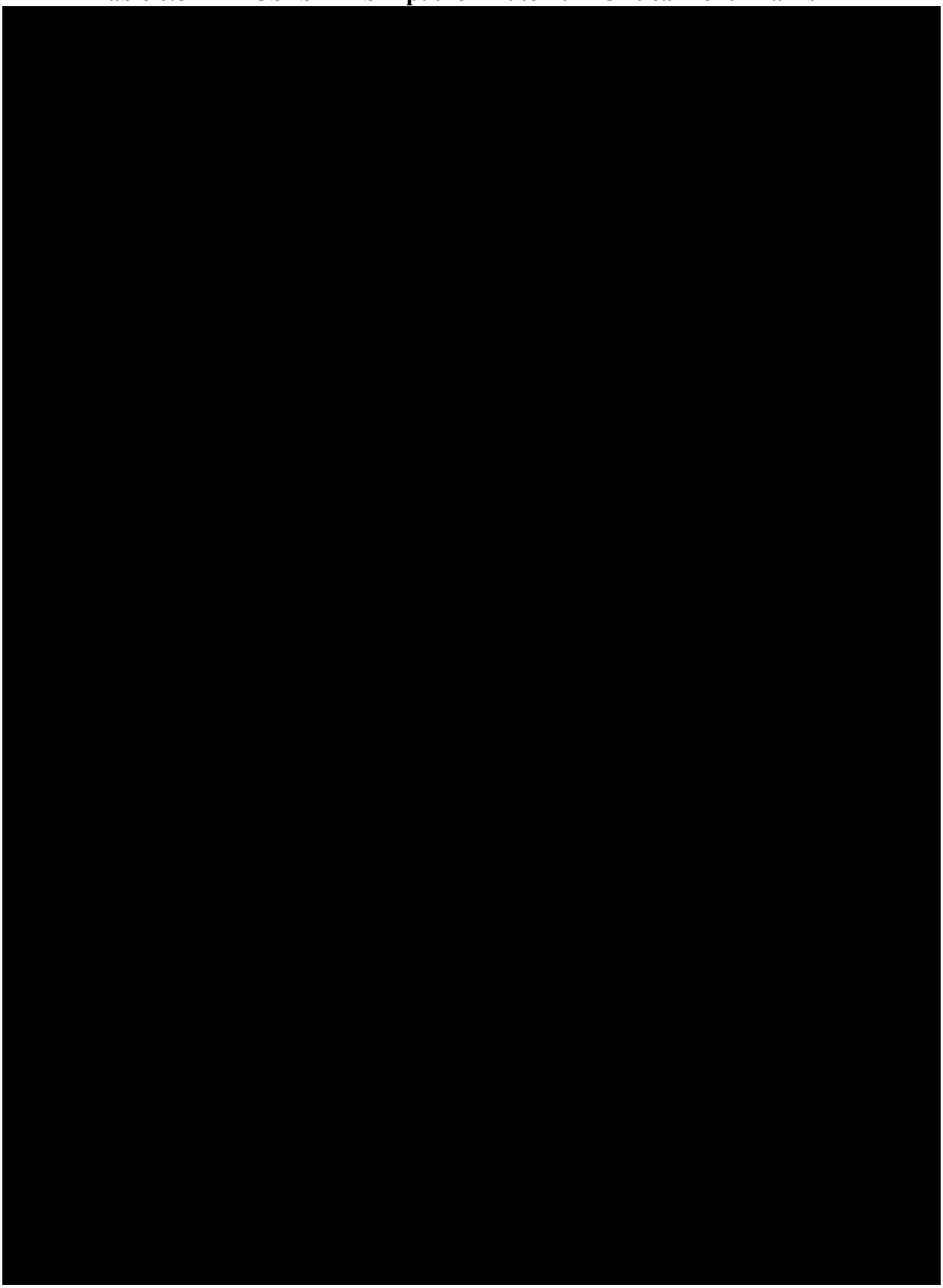
Table 6.8-9 Applicable USL Functions for FGE Configurations

[redacted]

Table 6.8-10 USL Functions for Low-Enriched Uranium Critical Benchmarks

[redacted]

Table 6.8-11 - USLSTATS Input for Plutonium Critical Benchmarks



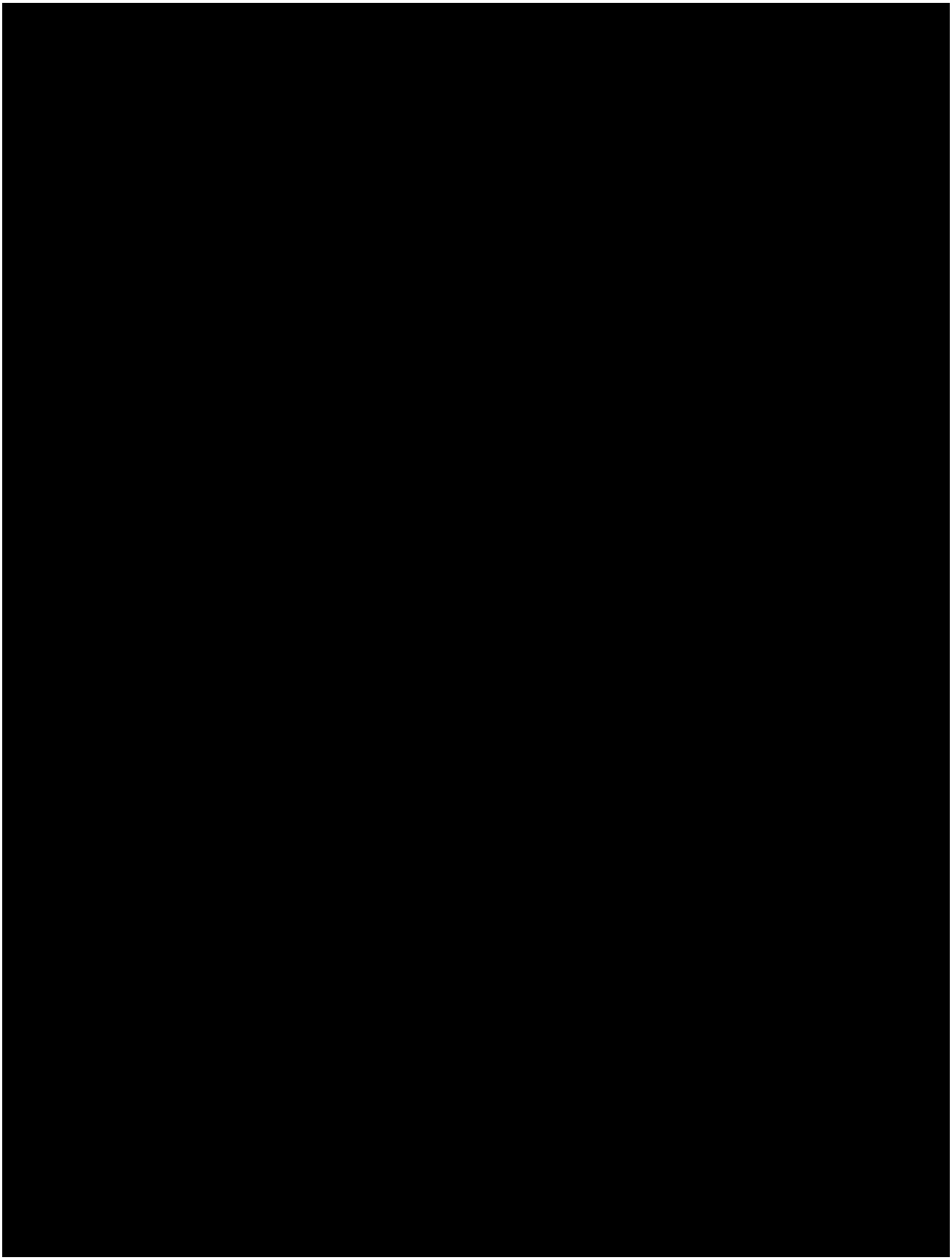
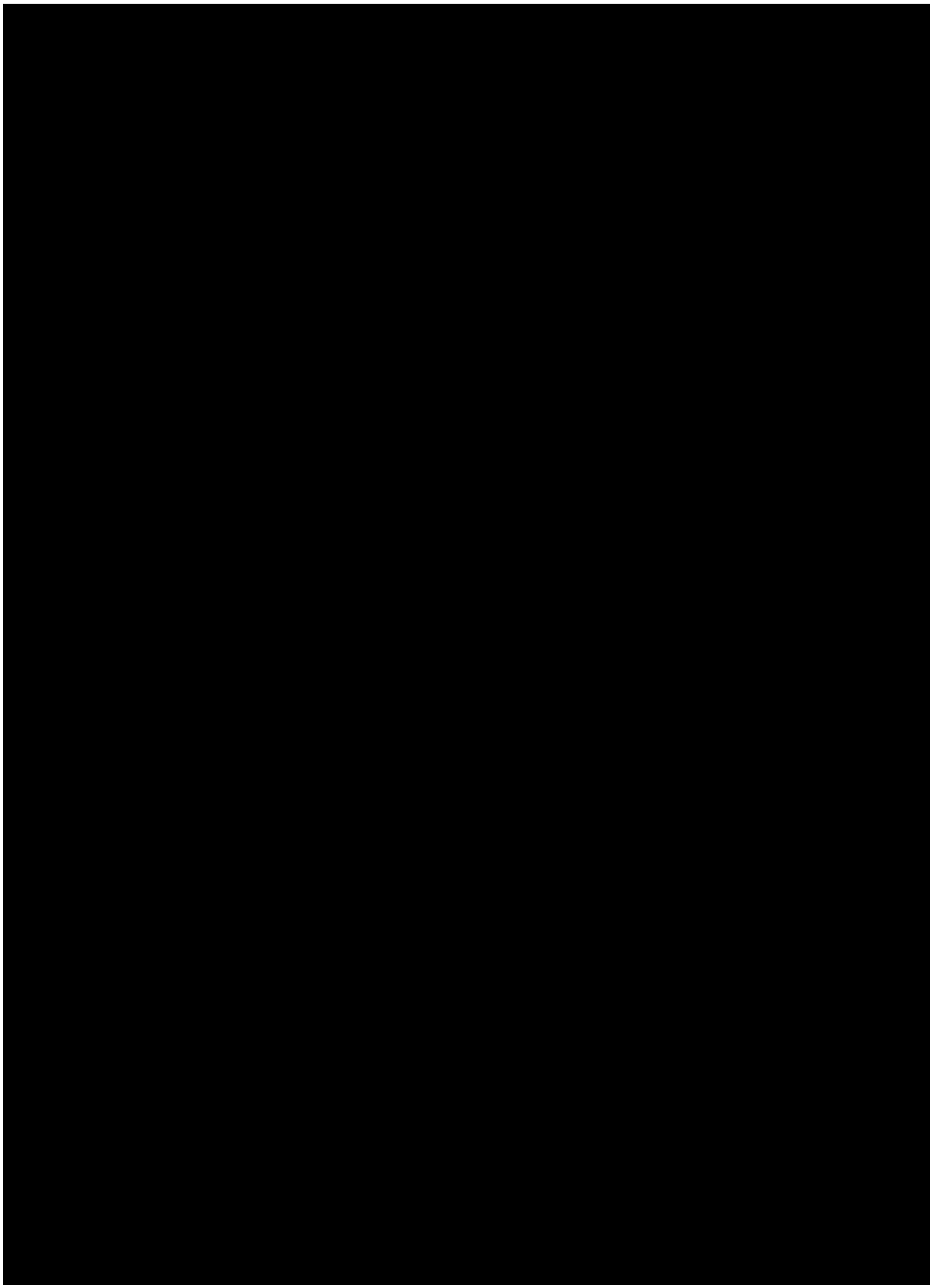


Table 6.8-12 - USLSTATS Input for Uranium Critical Benchmarks



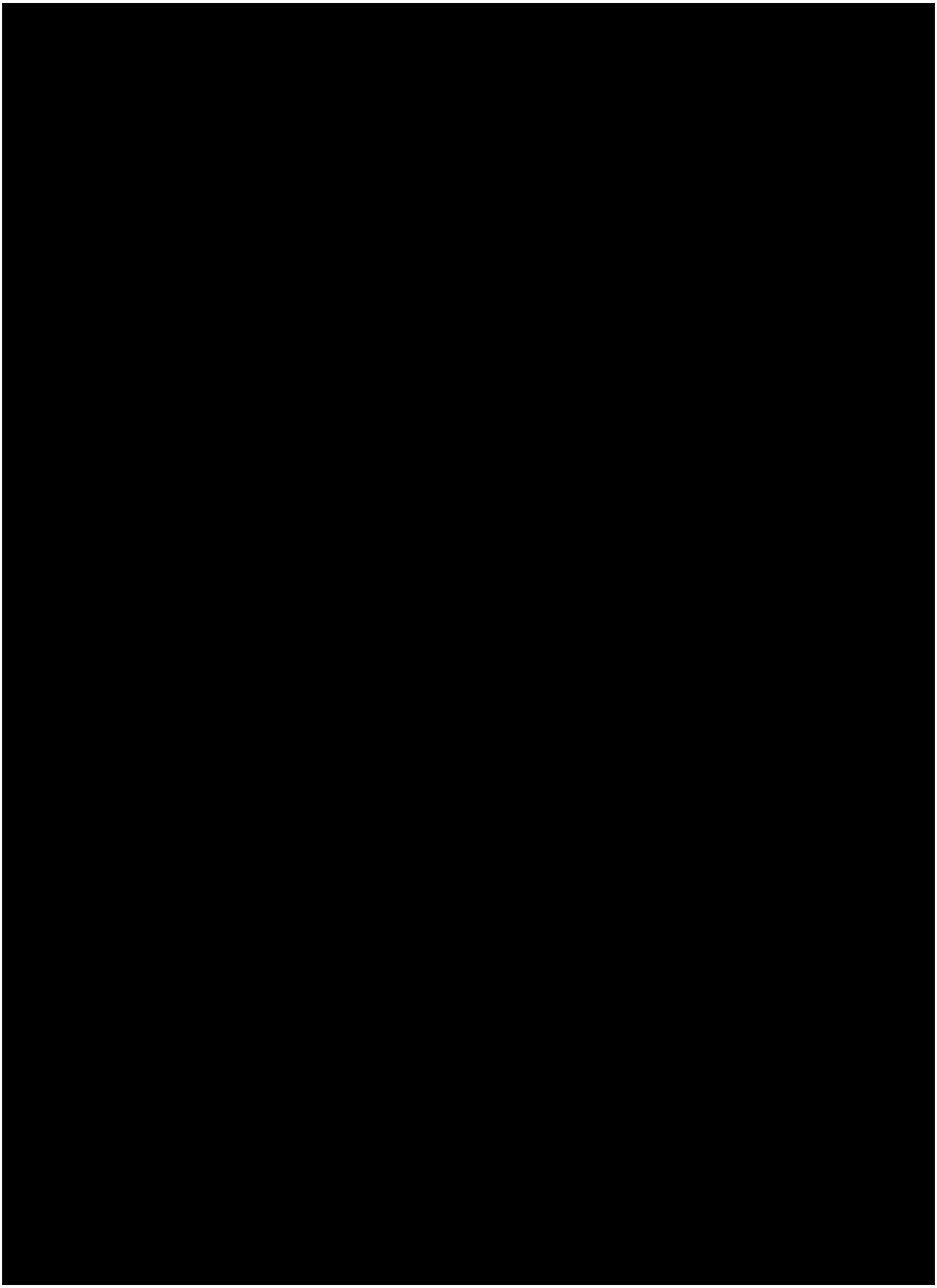


Figure 6.8-1 USLSTATS Plot of k_{norm} vs. EALF –Plutonium Solution Systems without Beryllium Reflector

Figure 6.8-2 USLSTATS Plot of k_{eff} vs. H/(^{239}Pu + ^{241}Pu) – Plutonium Systems without Beryllium Reflector

Figure 6.8-3 USLSTATS Plot of k_{eff} vs. Fissile Weight Percent – Plutonium Solution Systems without Beryllium Reflector

Figure 6.8-4 USLSTATS Plot of k_{norm} vs. EALF –Plutonium Solution Systems with Beryllium Reflector

Figure 6.8-5 USLSTATS Trend Plot of k_{eff} vs. H/(^{239}Pu + ^{241}Pu) –Plutonium Systems with Beryllium Reflector

Figure 6.8-6 USLSTATS Trend Plot of k_{eff} vs. Fissile Weight Percent –Plutonium Solution Systems with Beryllium Reflector

Figure 6.8-7 USLSTATS Plot of k_{norm} vs. EALF – Low-Enriched Uranium Systems

Figure 6.8-8 USLSTATS Plot of k_{norm} vs. H/^{235}U – Low-Enriched Uranium Systems

Figure 6.8-9 USLSTATS Plot of k_{norm} vs. ^{235}U Weight Percent – Low-Enriched Uranium Systems

6.9 Appendix

6.9.1 References

[6.1] Washington TRU Solutions LLC, "Test Plan to determine the TRU Waste Polyethylene Packing Fraction," WP 08-PT.09, Rev. 0, 2003.

[6.2] SAIC, "Reactivity Effects of Moderator and Reflector Materials on a Finite Plutonium System," SAIC-1322-001 Rev. 1, 2004.

[6.3] ASTM International, "Specification for General Requirements for Steel Plates for Pressures Vessels," SA-20/SA-20M, 2007.

[6.4] International Organization for Standardization, "Geometrical Product Specifcations (GPS) - Densional and Geometrical tolerances for moulded parts," ISO 8062-3, First Edition, 2007.

[6.5] Los Alamos National Laboratory, "Listing of Available ACE Data Tables," LA-UR-13-21822 Rev. 4, 2014.

[6.6] Pacific Northwest National Laboratory, "Compendium of Material Composition Data for Radiation Transport Modeling," PNNL-15870 Rev. 1, 2011.

[6.7] American Institute of Physics, "Isotopic Compositions of the Elements, 2001," 2005.

[6.8] Atomic Mass Data Center, "The Ame2003 Atomic Mass Evaluation," Nuclear Physics A 729 (2003) 336-676, December 22, 2003.

[6.9] ASTM International, "Standard Specification for Ferritic Ductile Iron Castings Suitable for Low-Temperature Service," A874/A874M - 98, 2014.

[6.10] American Society of Materials (ASM), "ASM Handbook, Cast Irons, Ductile Iron".

[6.11] [redacted].

[6.12] [redacted]

[6.13] American Nuclear Society, "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANSI/ANS-8.1-2014, 2014.

[6.14] [RESERVED]

[6.15] American Nuclear Society, "Nuclear Criticality Safety Control of Special Actinide Nuclides," ANSI/ANS-8.15-2014, 2014.

[6.16] Organization for Economic Cooperation and Development - Nuclear Energy Agency, "International Handbook of Evaluated Criticality Safety Benchmark Experiments," NEA/NSC/DOC(95)03, 2014.

[6.17] Oak Ridge National Laboratory, "Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages, NUREG/CR-6361, ORNL/TM-13211," NUREG/CR-6361, ORNL/TM-13211, 1997.

Chapter 7
Package Operations

Table of Contents

7 PACKAGE OPERATIONS 7-1

7.1 Package Loading 7.1-1
7.1.1 Preparation for Loading 7.1-1
7.1.2 Loading of Contents 7.1-4
7.1.3 Preparation for Transport 7.1-5

7.2 Package Unloading 7.2-1
7.2.1 Receipt of Package from Carrier 7.2-1
7.2.2 Removal of Contents 7.2-2

7.3 Preparation of Empty Packaging for Transport 7.3-1

7.4 Other Operations 7.4-1

7.5 Appendix 7.5-1
7.5.1 References 7.5-1
Attachment 7.5.1 - Demonstration of Compliance with Dose Rate Limits 7.5-2
Attachment 7.5.2 - Example CCV Pre-Shipment Inerting Procedure 7.5-60
Attachment 7.5-3 – Procedure for Determination of Flammable Gas Concentration and Shipping Time 7.5-63

List of Figures

Figure 7.5-1 Pre-Shipment Inerting Apparatus Schematic 7.5-62
Figure 7.5-2 CCV TRU Waste Contents/Gas Temperature vs. Decay Heat 7.5-66

List of Tables

Table 7-1 FGE Conversion Factors 7-3
Table 7.5-1 Bare Cask Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages) 7.5-4
Table 7.5-2 Bare Cask Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages) 7.5-12
Table 7.5-3 [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages) 7.5-18
Table 7.5-4 [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages) 7.5-26
Table 7.5-5 [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages) 7.5-32
Table 7.5-6 [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages) 7.5-40
Table 7.5-7 [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages) 7.5-46
Table 7.5-8 [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages) 7.5-54
Table 7.5-9 CCV Free Volume and Fill Gas Temperatures 7.5-66

7 PACKAGE OPERATIONS

This chapter outlines the operations used to load the OPTIMUS®-H transportation package and prepare it for transport (Section 7.1), unload the package (Section 7.2), and prepare the empty package for transport (Section 7.3). It presents the fundamental operating steps in the order in which they are performed. The operating steps are intended to ensure that the package is properly prepared for transport, consistent with the package evaluation in Chapters 2 through 6, and to ensure that occupational exposure rates are as low as reasonably achievable (ALARA).

The package shall be operated in accordance with detailed written procedures that are based on, and consistent with, the operations described in this section. To provide a comprehensive description of the package operations, this chapter describes a sequence for steps and refers to specific facility areas. The specific sequence and locations in the detailed written operating procedures may be tailored to meet facility requirements. Furthermore, the operating procedures in this section use standard rigging (e.g., swivel hoist rings and 3-leg bridles) to lift the packaging components. The use of alternative lifting devices in detailed written procedures is also acceptable, provided they satisfy the applicable site requirements.

It is the responsibility of the cask user to prepare detailed operating procedures based on the operating procedures described in this chapter, the requirements of the Certificate of Compliance, and any applicable site requirements. In addition, each licensee is responsible for providing advance notification in accordance with 10 CFR 71.97(b) for Type B shipments of quantities of normal form radioactive material being transported across a State boundary enroute to a disposal facility or to a collection point for transport to a disposal facility exceeding 3000 A_2.

All contents to be shipped shall satisfy the requirements for type and form of material, maximum quantity of contents per package, and loading restrictions described in Section 1.2.2. Compliance with dose rate limits shall be demonstrated in accordance with Attachment 7.5-1. Irradiated CANDU fuel contents meeting the limits determined in Appendix 5.5.4, Table 5.5-10 are exempt from the requirements of Attachment 7.5-1. Furthermore, the total radioactive decay heat of the contents shall not exceed 200 watts for TRU waste (Contents 1-1, 1-2A, 1-2B, and 1-2C) or 1,500 watts for irradiated fuel waste (Contents 2-1 and 2-2). Any TRU waste content with a total radioactive decay heat exceeding 50 watts shall be inerted in accordance with Attachment 7.5-2.

For TRU waste contents that could radiolytically generate combustible gases (Content 1-1), compliance with the flammable gas concentration limits shall be demonstrated in accordance with Attachment 7.5-3.

For converting isotopes to a Fissile Gram Equivalent (FGE) ^{239}Pu, the conversion factors presented in Table 7-1 shall be used. Note that only the isotopes listed in Table 7-1 need to be considered for the total FGE mass determination. The total FGE mass of the contents is calculated as the sum of the isotope mass times the respective FGE conversion factor for each isotope listed in Table 7-1. The calculated total FGE mass must be less than the respective limit to be acceptable for shipment.

Table 7-1 - FGE Conversion Factors

Isotope	ANSI Limit (kg)	FGE Conversion [1]	Reference	
			Standard	Location
Pu-239	0.45	1.000E+00	8.1 [7.3]	§5.2
U-233	0.5	9.000E-01		
U-235	0.7	6.429E-01		
Pu-236	0.6	7.500E-01	8.15 [7.4]	Table 2
Pu-238	5.1	8.824E-02		Table 1
Pu-241	0.185	2.432E+00		Table 2
Pu-242	55	8.182E-03		Table 1
U-232	1	4.500E-01		Table 1
U-234	59	7.627E-03		Table 1
Np-237	35	1.286E-02		Table 1
Am-241	24	1.875E-02		Table 1
Am-242m	0.011	4.091E+01		Table 2
Am-243	65	6.923E-03		Table 1
Cm-242	6	7.500E-02		Table 1
Cm-243	0.09	5.000E+00		Table 2
Cm-244	11	4.091E-02		Table 1
Cm-245	0.023	1.957E+01		Table 2
Cm-246	16	2.813E-02		Table 1
Cm-247	0.5	9.000E-01		Table 2
Cf-249	0.01	4.500E+01		Table 2
Cf-251	0.005	9.000E+01		Table 2

Note: [1] For any non-uranium or non-plutonium isotopes, if there are multiple isotopes of the same element present in the contents, the highest conversion factor for the given element should be used.

This page intentionally left blank.

7.1 Package Loading

This section describes loading-related preparations, tests, and inspections for the package. These include the inspections made before loading the package to determine that it is not damaged, and that radiation and surface contamination levels are within the regulatory limits.

7.1.1 Preparation for Loading

This section describes the operations for preparing the package for loading. It is the responsibility of the cask user to verify that the contents are authorized in accordance with the package approval and that the package is loaded and closed in accordance with detailed written procedures that are based on the operating procedures described in this chapter, the requirements of the Certificate of Compliance, and any applicable site requirements.

The transportation package is transported by highway, rail and sea in a vertical orientation. The package may either be tied down to a custom-designed pallet that is secured to the deck of the transport vehicle or the floor of an ISO container, or it may be tied down directly to the deck of the transport vehicle. For some operations, the different tiedown, transport vehicle, and lifting/handling configurations require differences in the procedural steps, which are described in the following procedure.

Loading operations shall be performed in a precipitation-free environment, or measures shall be taken to prevent precipitation from entering the package cavities, such as performing loading operations under a protective cover. If standing water collects inside the CCV cavity and/or SIA cavity (if used), absorbent materials or another suitable method, such as a vacuum system, shall be used to remove the free-standing water from the CCV cavity and/or SIA cavity (if used), which may require the contents to be unloaded.

The only special equipment required for the loading and unloading operations of the package, other than standard sockets and wrenches for fasteners, equipment used to lift the packaging components, a radioactive contamination detector, and a radiation survey meter, are the pre-shipment inerting and leakage rate testing apparatuses.

Appropriate controls shall be used for all loading and unloading operations to prevent the spread of radioactive contamination and protect personnel from exposure to excessive radiation.

The general procedure for preparing each package for loading is as follows:

1. Upon receipt of the package, perform radiation and removable contamination surveys of the package in accordance with facility procedures and the requirements of

49 CFR 173.441 and 49 CFR 173.443. Clean or decontaminate the package as necessary in accordance with facility procedures.

2. Move the transport vehicle with the package(s) to the receiving area and secure the transport vehicle.

3. Visually inspect the exterior surfaces of the package for any signs of damage to verify that the package is in unimpaired physical condition.

4. Remove the tamper-indicating seal from the upper impact limiter.

5. If the package is to remain on the transport vehicle for loading operations proceed to Step 7.

6. If the package is to be removed from the transport vehicle using a forklift, detach the pallet from the transport vehicle but do not remove the tiedowns that secure the package to the pallet, engage the pallet with the forklift, lift the package off the transport vehicle, and move the package to the designated loading area.

7. Loosen the nuts on the upper impact limiter swing bolts and rotate the swing bolts clear of the OSV attachment brackets.

8. Remove plugs from the upper impact limiter lifting attachment holes.

9. Attach rigging to the upper impact limiter lifting attachments.

10. Lift the upper impact limiter vertically to expose the top end of the OSV and move it to the designated storage location.

11. If the package is to be removed from the transport vehicle using a crane or if the OSV is to be removed from the lower impact limiter perform the following steps, otherwise proceed to Step 12.

    a. Detach and remove the tiedowns from the OSV body.

    b. Loosen the nuts on the lower impact limiter swing bolts and rotate the swing bolts clear of the OSV attachment brackets.

    c. Using a lifting yoke attached to the two OSV lifting trunnions or suitable rigging attached to two diagonally opposed OSV tiedown lugs, lift the OSV vertically to remove it from the lower impact limiter and move the OSV to the designated loading area.

12. Install work platforms or scaffolding around the packaging, if required, to provide access to the top end of the OSV and CCV.

13. Loosen and remove all [redacted] OSV closure bolts.

14. Attach swivel hoist rings (SHRs) to the OSV lid and torque SHRs in accordance with the manufacturer's instructions.

15. Attach suitable rigging to the SHRs on the OSV lid.

16. Lift the OSV lid vertically and move it to the designated temporary storage location.

17. Loosen all [redacted] CCV closure bolts.

18. Attach swivel hoist rings (SHRs) to the CCV lid and torque SHRs in accordance with the manufacturer's instructions.

19. Attach suitable rigging to the SHRs on the CCV lid.

20. Verify that the captured lid bolts are completely disengaged from the threaded holes in the CCV bolt flange.

Caution: When handling the CCV lid, the O-ring and associated sealing surfaces shall be protected from damage.

21. Lift the CCV lid vertically and move it to the designated temporary storage location.

Caution: When handling the CCV port covers, the O-ring and associated sealing surfaces shall be protected from damage.

22. If required, loosen and remove all [redacted] CCV port cover bolts and remove the CCV port cover and place it in the designated temporary storage location.

23. Remove the plugs from the CCV lid and port cover test ports and place them in the temporary storage location.

24. Visually inspect the CCV lid and CCV port cover O-ring seals for signs of damage or defects (e.g., cracks, tears, cuts, or discontinuities) that may prevent them from sealing properly when the package is assembled. Replace any damaged or defective O-ring seals with new O-ring seals in accordance with the requirements of the Maintenance Program described in Section 8.2.3.1.

Note: A maintenance leakage rate test is required for any replaced CCV lid or vent port containment O-ring, per Section 8.2.2.1.

25. Coat the exposed surfaces of the CCV lid and CCV port cover O-ring seals with the vacuum grease prior to assembling the package to minimize deterioration or cracking of the seal during use. Remove excess vacuum grease from the O-ring and fastener seals prior to assembling the package.

26. Visually inspect the CCV lid bolts, CCV port cover bolts, and test port plugs for signs of excessive wear and/or damage. Repair or replace any damaged bolts in accordance with the requirements of the Maintenance Program described in Section 8.2.3.3.

27. If a [redacted] SIA is inside the CCV cavity and will be used for the shipment, attached suitable rigging to the SIA lid, lift the SIA lid vertically and move it to the temporary storage location.

Caution: When lowering packaging internals inside the CCV cavity, protect the CCV body bolt flange sealing surface from damage (e.g., scratches or gouges).

28. If an SIA is not inside the CCV cavity, but is required for the shipment, use suitable rigging to lift and lower the required dunnage and SIA body into the CCV cavity.

7.1.2 Loading of Contents

This section describes the operations for loading the contents into the package and closing the package. The general procedure for loading the contents into the package and closing each package is as follows:

1. Confirm that the contents to be loaded meet the requirements of the Certificate of Compliance.

2. Verify that the packaging internals (e.g., cribbing/dunnage and SIA components) required for the shipment are properly configured in the CCV cavity.

Caution: When lowering the contents into the CCV or SIA cavity, protect the CCV body bolt flange sealing surface from damage (e.g., scratches or gouges).

3. Lower the contents into the CCV cavity or SIA cavity (if used).

Caution: When lowering the SIA lid onto the SIA body inside the CCV cavity, protect the CCV body bolt flange sealing surface from damage (e.g., scratches or gouges).

4. If a [redacted] SIA is used for the shipment, lift the SIA lid and carefully lower it onto the SIA body inside the CCV cavity. Remove the rigging from the SIA lid.

5. Clean and visually inspect the sealing surface for the CCV lid (i.e., the area of the CCV body bolt flange inboard of the CCV lid bolt holes) and the CCV port cover (i.e., the area of the CCV lid port opening inboard of the CCV port cover bolt holes) for wear and/or damage (e.g., scratches, gouges, nicks, cracks, etc.) that may prevent the containment O-rings and fastener seals from sealing properly.

6. Coat the CCV closure bolt threads with thread lubricant.

7. Lift the CCV lid, position it over the alignment pins on the CCV body, and carefully lower it onto the CCV body.

8. Remove the SHRs from the CCV lid.

9. Tighten each of the CCV lid bolts, in the sequence shown on the CCV lid, to a torque of 300 ± 15 ft-lbs and repeat the sequence to verify that all CCV lid bolts are tightened to the required torque.

10. If the package is loaded with contents having a total heat load greater than 50 watts, evacuate the CCV cavity and contents to an oxygen content of 1% or less, then backfill with helium gas.

11. If removed, install the CCV port cover and torque the port cover bolts to 15± 1 in-lbs.

7.1.3 Preparation for Transport

This section describes the operations for preparing the package for transport, including pre-shipment leakage rate tests, radiation and contamination surveys, measurement of the package surface temperature, securement of the package, and application of tamper-indicating devices. The general procedure for preparing each package for transport is as follows:

1. Perform the pre-shipment leakage rate test of the CCV lid and port cover O-ring seals in accordance with a written procedure that satisfies the requirements of Section 8.2.2.2.

2. Install the plugs in the leak test ports of the CCV lid and CCV port cover.

3. Decontaminate the exterior top surface of the CCV as necessary.

4. Install the OSV lid onto the OSV body and tighten each of the OSV lid bolts, in the sequence shown on the OCV lid, to a torque of 300 ± 15 ft-lbs and repeat the sequence to verify that all OSV lid bolts are tightened to the required torque.

5. Remove the SHRs from the OSV lid.

6. If the OSV was removed from the lower impact limiter for loading operations, perform the following steps, otherwise proceed to Step 7.

   a. Using a lifting yoke attached to the two OSV lifting trunnions or suitable rigging attached to two diagonally opposed OSV tiedown lugs, lift the OSV, align the OSV with the lower impact limiter, and carefully lower it into position in the lower impact limiter.

   b. Attach the lower impact limiter swing bolts to the OSV attachment brackets, tighten each of the impact limiter attachment nuts to a torque of 50 ± 5 ft-lbs, then tighten each of the impact limiter attachment jam nuts to a torque of 50 ± 5 ft-lbs.

7. If the package was removed from the transport vehicle for loading operations, is not already secured to a pallet and a pallet is to be used for handling and transport, perform the following steps, otherwise proceed to Step 8.

   a. Using a lifting yoke attached to the two OSV lifting trunnions or suitable rigging attached to two diagonally opposed OSV tiedown lugs, lift the OSV with the lower impact limiter attached, and carefully lower it into position in the pallet.

   b. Install the tiedowns between the OSV body tiedown lugs and the pallet tiedown lugs.

   c. Lift the upper impact limiter vertically to position it on the top end of the OSV.

   d. Detach/remove the rigging from the upper impact limiter.

   e. If the package is to be transported on an open transport vehicle, install plugs in the impact limiter lifting attachment holes.

   f. Attach the upper impact limiter swing bolts to the OSV attachment brackets, tighten each of the impact limiter attachment nuts to a torque of 50 ± 5 ft-lbs, then tighten each of the impact limiter attachment jam nuts to a torque of 50 ± 5 ft-lbs.

g. Using a forklift, lift the package and position it on the deck of the transport vehicle or inside the ISO container.

h. Secure the pallet to the deck of the transport vehicle or floor of the ISO container.

8. If the package was removed from the transport vehicle for loading operations and is to be secured directly to the transport vehicle, perform the following steps, otherwise proceed to Step 9.

   a. Using a lifting yoke attached to the two OSV lifting trunnions or suitable rigging attached to two diagonally opposed OSV tiedown lugs, lift the OSV with the lower impact limiter attached, and position it on the deck of the transport vehicle.

   b. Install the tiedowns between the OSV body tiedown lugs or trunnions and the transport vehicle.

   c. Lift the upper impact limiter vertically to position it on the top end of the OSV.

   d. Detach/remove the rigging from the upper impact limiter.

   e. If the package is to be transported on an open transport vehicle, install plugs in the impact limiter lifting attachment holes.

   f. Attach the upper impact limiter swing bolts to the OSV attachment brackets, tighten each of the impact limiter attachment nuts to a torque of 50 ± 5 ft-lbs, then tighten each of the impact limiter attachment jam nuts to a torque of 50 ± 5 ft-lbs.

9. If the package was loaded while secured to the transport vehicle, perform the following steps, otherwise proceed to Step 10.

   a. Lift the upper impact limiter vertically to position it on the top end of the OSV.

   b. Detach/remove the rigging from the upper impact limiter.

   c. If the package is to be transported on an open transport vehicle, install plugs in the impact limiter lifting attachment holes.

   d. Attach the upper impact limiter swing bolts to the OSV attachment brackets, tighten each of the impact limiter attachment nuts to a torque of 50 ± 5 ft-lbs, then tighten each of the impact limiter attachment jam nuts to a torque of 50 ± 5 ft-lbs.

10. Install the tamper-indicating devices on the package.

11. Verify external radiation levels do not exceed the limits of 49 CFR 173.441(b).

12. Verify the levels of non-fixed contamination on the package do not exceed the limits of 49 CFR 173.443(a)(1).

13. Verify the exterior surface of the package does not exceed 85°C (185°F) in accordance with the requirement of 49 CFR 173.442(b)(2).

14. Verify the package marking and labeling meets the requirements of 49 CFR 172.

15. If shipping the package in an ISO container, close and secure the ISO container, lift and position the ISO container onto the transport chassis, then secure the ISO container to the transport chassis.

16. If contents require shipment under exclusive use controls, provide specific written instructions for maintenance of the exclusive use shipment controls to the carrier in accordance with the requirements of 49 CFR 173.441(c).

7.2 Package Unloading

This section describes the package unloading operations, including the inspections, tests, and preparations of the transportation package for unloading.

7.2.1 Receipt of Package from Carrier

This section describes the procedure for receiving a loaded package, including radiation and contamination surveys and inspection of tamper-indicating devices. The general procedure for receipt of each loaded package from a Carrier is as follows:

1. Perform a radiation survey of the package. If the external surface radiation levels exceed 200 mrem/hr, then notify the Consignor immediately and investigate the cause of the high radiation levels before proceeding.

2. Perform a contamination survey of the external surfaces of the package to confirm that the levels of non-fixed (removable) radioactive contamination does not exceed the limits specified in 49 CFR 173.443. If contamination levels exceed the limits, then notify the Consignor immediately and decontaminate the exterior surfaces, as necessary.

3. Visually verify that the tamper-indicating seals are intact. If it is NOT intact, investigate the cause and take actions per facility procedures.

4. Move the transport vehicle with the package(s) to the receiving area and secure the transport vehicle.

5. Remove the tamper-indicating seals from the packaging(s).

Note: Repeat the following steps for each package to be unloaded.

6. If the package is to be removed from the transport vehicle using a forklift, perform the following steps, otherwise proceed to Step 7.

   a. Detach the pallet from the transport vehicle but do not remove the tiedowns that secure the package to the pallet.

   b. Engage the pallet with the forklift, lift the package off the transport vehicle, and move the package to the loading area.

7. Loosen the nuts on the upper impact limiter swing bolts and rotate the swing bolts clear of the OSV attachment brackets.

8. Remove the plugs from the upper impact limiter lifting attachment holes.

9. Attach rigging to the upper impact limiter lifting attachments.

10. Lift the upper impact limiter vertically to expose the top end of the OSV and move it to the designated storage location.

11. If the package is to be removed from the transport vehicle or lower impact limiter for unloaded operations perform the following steps, otherwise proceed to Step 12.

    a. Detach and remove the tiedowns from the OSV body.

    b. Loosen the nuts on the lower impact limiter swing bolts and rotate the swing bolts clear of the OSV attachment brackets.

    c. Using a lifting yoke attached to the two OSV lifting trunnions or suitable rigging attached to two diagonally opposed OSV tiedown lugs, lift the OSV vertically to remove it from the lower impact limiter and move the OSV to the designated loading area.

12. Install work platforms or scaffolding around the packaging, if required, to provide access to the top end of the OSV and CCV.

7.2.2 Removal of Contents

This section describes the procedure for opening and removing the contents from a loaded package. The general procedure for opening a loaded package and removing the contents from each package is as follows:

Note: Repeat the following steps for each package to be unloaded.

1. Loosen and remove all [redacted] OSV closure bolts.

2. Attach swivel hoist rings (SHRs) to the OSV lid and torque SHRs in accordance with the manufacturer's instructions.

3. Attach suitable rigging to the SHRs on the OSV lid.

4. Lift the OSV lid vertically and move it to the temporary storage location.

5. Loosen all [redacted] CCV closure bolts.

6. Attach swivel hoist rings (SHRs) to the CCV lid and torque SHRs in accordance with the manufacturer's instructions.

7. Attach suitable rigging to the SHRs on the CCV lid.

8. Verify that the captured lid bolts are completely disengaged from the threaded holes in the CCV bolt flange.

Caution: When handling the CCV lid, the O-rings and associated sealing surfaces shall be protected from damage.

9. Lift the CCV lid vertically and move it to the designated temporary storage location.

10. If a [redacted] SIA is inside the CCV cavity, attached suitable rigging to the SIA lid, lift the SIA lid vertically and move it to the temporary storage location.

11. Remove the contents from the packaging.

This page intentionally left blank.

7.3 Preparation of Empty Packaging for Transport

This section describes the procedure for preparing a previously used and empty package for transport, including the inspections, tests, and special preparations needed to ensure that the packaging is verified to be empty, is properly closed, and that the radiation and contamination levels are within the applicable allowable limits. The general procedure for preparing each empty package for transport is as follows:

1. Visually inspect the CCV cavity or SIA cavity to confirm that it has been emptied of its contents as far as practical.

2. Survey the interior of the internal surfaces of the package (i.e., CCV cavity, CCV flange, and underside of the CCV lid) and any empty payload internals (e.g., SIA body, lid, and dunnage, if used) to be shipped to verify that the interior contamination limits of 49 CFR 173.428(d) are satisfied. If the non-fixed surface contamination exceeds the limits for empty package shipment, then decontaminate the interior surfaces, as necessary.

3. Visually inspect the readily accessible surfaces of the packaging components for any signs of damage that may have occurred during prior use to verify that the package is in unimpaired physical condition.

4. Apply thread lubricant to the threaded fasteners of the package.

Caution: When lowering the SIA lid onto the SIA body inside the CCV cavity, protect the CCV body bolt flange sealing surface from damage (e.g., scratches or gouges).

5. If a [redacted] SIA is used, lift and lower the SIA lid onto the SIA body inside the CCV cavity.

6. Install the CCV closure lid and tighten each of the [redacted] CCV lid bolts, in the sequence shown on the CCV lid, to a torque of 300 ± 15 ft-lbs, then repeat the sequence to verify that all CCV lid bolts are tightened to the required torque.

7. Remove the SHRs from the CCV lid.

8. If the CCV port cover has been removed from the CCV lid, install the CCV port cover.

9. Torque each of the [redacted] port cover bolts to 15 ± 1 in-lbs.

10. Install the OSV lid and tighten each of the [redacted] OSV lid bolts, in the sequence shown on the OSV lid, to a torque of 300 ± 15 ft-lbs, then repeat the sequence to verify that all OSV lid bolts are tightened to the required torque.

11. Remove the SHRs from the OSV lid.

12. If the package was unloaded while secured to the transport vehicle, perform the following steps, otherwise proceed to Step 13.

    a. Lift the upper impact limiter vertically to position it on the top end of the OSV.

    b. Detach/remove the rigging from the upper impact limiter.

    c. If the package is to be transported on an open transport vehicle, install plugs in the impact limiter lifting attachment holes.

    d. Attach the upper impact limiter swing bolts to the OSV attachment brackets, tighten each of the impact limiter attachment nuts to a torque of 50 ± 5 ft-lbs, then tighten each of the impact limiter attachment jam nuts to a torque of 50 ± 5 ft-lbs.

13. If the OSV was removed from the lower impact limiter for unloading operations, perform the following steps, otherwise proceed to Step 14.

    a. Using a lifting yoke attached to the two OSV lifting trunnions or suitable rigging attached to two diagonally opposed OSV tiedown lugs, lift the OSV, align the OSV with the lower impact limiter, and carefully lower it into position in the lower impact limiter.

    b. Attach the lower impact limiter swing bolts to the OSV attachment brackets, tighten each of the impact limiter attachment nuts to a torque of 50 ± 5 ft-lbs, then tighten each of the impact limiter attachment jam nuts to a torque of 50 ± 5 ft-lbs.

14. If the package was removed from the transport vehicle for unloading operations, is not already secured to a pallet and a pallet is to be used for handling and transport, perform the following steps, otherwise proceed to Step 15.

    a. Using a lifting yoke attached to the two OSV lifting trunnions or suitable rigging attached to two diagonally opposed OSV tiedown lugs, lift the OSV with the lower impact limiter attached, and carefully lower it into position in the pallet.

    b. Install the tiedowns between the OSV body tiedown lugs and the pallet tiedown lugs.

c. Lift the upper impact limiter vertically to position it on the top end of the OSV.

d. Detach/remove the rigging from the upper impact limiter.

e. If the package is to be transported on an open transport vehicle, install plugs in the impact limiter lifting attachment holes.

f. Attach the upper impact limiter swing bolts to the OSV attachment brackets, tighten each of the impact limiter attachment nuts to a torque of 50 ± 5 ft-lbs, then tighten each of the impact limiter attachment jam nuts to a torque of 50 ± 5 ft-lbs.

g. Using a forklift, lift the package and position it on the deck of the transport vehicle or inside the ISO container.

h. Secure the pallet to the transport vehicle or ISO container.

15. If the package was removed from the transport vehicle for unloading operations and is to be secured directly to the transport vehicle, perform the following steps, otherwise proceed to Step 16.

    a. Using a lifting yoke attached to the two OSV lifting trunnions or suitable rigging attached to two diagonally opposed OSV tiedown lugs, lift the OSV with the lower impact limiter attached, and position it on the deck of the transport vehicle.

    b. Install the tiedowns between the OSV body tiedown lugs or trunnions and the transport vehicle.

    c. Lift the upper impact limiter vertically to position it on the top end of the OSV.

    d. Detach/remove the rigging from the upper impact limiter.

    e. If the package is to be transported on an open transport vehicle, install plugs in the impact limiter lifting attachment holes.

    f. Attach the upper impact limiter swing bolts to the OSV attachment brackets, tighten each of the impact limiter attachment nuts to a torque of 50 ± 5 ft-lbs, then tighten each of the impact limiter attachment jam nuts to a torque of 50 ± 5 ft-lbs.

16. Install the tamper-indicating devices on the package.

17. Perform a radiation survey to confirm that the dose rates on the external surfaces of each package does not exceed 0.005 mSv/hour (0.5 mrem/hour) in accordance with the 49 CFR 71.421(a)(2).

18. Perform a contamination survey to confirm that the non-fixed (removable) radioactive surface contamination on the external surfaces of each do not exceed the limits specified in 40 CFR 173.443(a). If the non-fixed surface contamination exceeds the limits, then decontaminate the interior surfaces, as necessary.

19. Cover the packaging marking and labelling with an "Empty" label as prescribed in 49 CFR 172.450.

20. If shipping the package in an ISO container, when all empty packaging(s) have been secured inside the ISO container, close and secure the ISO container, lift and position the ISO container onto the transport chassis, then secure the ISO container to the transport chassis.

21. Release the package to the Carrier for the return shipment.

7.4 Other Operations

Not applicable.

This page intentionally left blank.

7.5 Appendix

7.5.1 References

[7.1] ANSI N14.5-2014, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*, American National Standards Institute, Inc., June 19, 2014.

[7.2] Savannah River National Laboratory, Report No. SRNL-STI-2016-00674, *Proof of Principle Testing For Inerting a 9978 Containment Vessel*, November 2016.

[7.3] American Nuclear Society, "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANSI/ANS-8.1-2014, 2014.

[7.4] American Nuclear Society, "Nuclear Criticality Safety Control of Special Actinide Nuclides," ANSI/ANS-8.15-2014, 2014.

Attachment 7.5-1
Demonstration of Compliance with Dose Rate Limits

(see Section 5.4.4.3 for the discussion on demonstrating compliance with dose rate limits)

1. Determine the total activity of each isotope in the contents.

2. Demonstrate compliance with 10CFR71 dose rate limits using Compliance Method 1 or Compliance Method 2.

   Compliance Method 1 (see Section 5.4.4.3.2)

   a. Calculate the total dose for each isotope in the contents (including all decay products) for NCT at the top, bottom and side of the package surface, at the transport vehicle surface, and a the 1-meter and 2-meter locations, as applicable, and for HAC at 1-meter from the top, bottom and side surfaces based on the activity of each isotope in the contents and the Dose Rate/Ci values listed in Tables 7.5-1 (exclusive use) and 7.5-2 (nonexclusive use) for the bare cask, in Table 7.5-3 (exclusive use) and 7.5-4 (nonexclusive use) with the [redacted]A, in Table 7.5-5 (exclusive use) and 7.5-6 (nonexclusive use) with the [redacted] and in Table 7.5-7 (exclusive use) and 7.5-8 (nonexclusive use) with the [redacted][1], as applicable. Calculate the total dose rates at the package surfaces, transport vehicle surface, 1-meter, 2-meter, and HAC 1-meter surfaces, as applicable, as the sum of the dose rates for each isotope at the respective location using Equation 4 from Section 5.4.1.3.

   b. If the calculated dose rates are less than the respective limits for the package surface, transport vehicle surface, 2-meter, and HAC 1-meter locations (i.e., conservatively taken as 90% of the regulatory dose rate limits), compliance with external dose rate limits has been demonstrated and the package analyzed can be shipped in the analyzed configuration. If the total dose rates exceed any of the respective limits then repeat Steps 2a and 2b for the shipping configuration that includes the appropriate SIA.

      Note: if any dose rate value is rounded, it should always be rounded up to ensure the calculated dose rates never exceed their respective limits due to rounding.

   Compliance Method 2 (see Section 5.4.4.3.3)

   a. Calculate the activity limit for each isotope in the contents, by dividing 90% of the dose rate limit at each location (e.g. 9 mrem/hr at 2-meters) by the Dose Rate/Ci value for the respective location calculated in Step 2. The overall activity limit for each isotope is set as the minimum value based on all regulatory dose rate locations. Predetermined activity

[redacted]

limits are provided in Tables 7.5-1 (exclusive use) and 7.5-2 (nonexclusive use) for the bare cask, in Table 7.5-3 (exclusive use) and 7.5-4 (nonexclusive use) with the [redacted], in Table 7.5-5 (exclusive use) and 7.5-6 (nonexclusive use) with the [redacted] and in Table 7.5-7 (exclusive use) and 7.5-8 (nonexclusive use) with the [redacted]

b. Calculate the sum of the fractions for the contents (see Section 5.4.4.3.3). For each isotope, divide the total activity determined in Step 1 by the activity limit for the isotope calculated in part a. Sum the fractions from all isotopes in the contents to calculate the sum of the fractions.

c. To demonstrate compliance with all regulatory dose rate limits, the sum of the fractions from all isotopes in the contents must be less than 1.0.

Table 7.5-1 – Bare Cask Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Ac225	3.031E-04	3.519E-04	6.675E-04	1.544E-04	2.001E-05	5.435E-06	1.508E-04	1.751E-04	1.600E-04	2.697E+03	3.312E+03
Ac227	2.082E-06	2.322E-06	4.522E-06	1.060E-06	1.383E-07	3.781E-08	1.036E-06	1.152E-06	1.086E-06	3.981E+05	4.760E+05
Ac228	3.943E-01	5.173E-01	1.000E+00	2.246E-01	2.964E-02	8.078E-03	2.282E-01	2.996E-01	2.487E-01	1.799E+00	2.228E+00
Ag108	2.293E-03	3.277E-03	5.624E-03	1.208E-03	1.518E-04	4.076E-05	1.193E-03	1.720E-03	1.347E-03	3.201E+02	4.416E+02
Ag108m	1.648E-01	2.353E-01	4.048E-01	8.679E-02	1.095E-02	2.912E-03	8.525E-02	1.229E-01	9.645E-02	4.447E+00	6.181E+00
Ag110	1.542E-02	2.070E-02	3.879E-02	8.634E-03	1.124E-03	3.053E-04	8.711E-03	1.171E-02	9.580E-03	4.641E+01	5.895E+01
Ag110m	1.118E+00	1.471E+00	2.832E+00	6.354E-01	8.353E-02	2.269E-02	6.445E-01	8.497E-01	7.037E-01	6.355E-01	7.932E-01
Am241	2.095E-04	2.293E-04	4.532E-04	1.068E-04	1.399E-05	3.817E-06	1.043E-04	1.139E-04	1.089E-04	3.972E+03	4.716E+03
Am242	3.087E-06	4.962E-06	7.217E-06	1.500E-06	1.818E-07	4.876E-08	1.479E-06	2.401E-06	1.739E-06	2.494E+05	3.692E+05
Am242m	1.821E-06	1.998E-06	3.962E-06	9.337E-07	1.224E-07	3.343E-08	9.193E-07	1.005E-06	9.604E-07	4.544E+05	5.385E+05
Am243	1.812E-04	1.985E-04	3.920E-04	9.239E-05	1.210E-05	3.304E-06	9.025E-05	9.860E-05	9.418E-05	4.592E+03	5.447E+03
Am245	4.150E-05	6.725E-05	9.665E-05	2.007E-05	2.443E-06	6.531E-07	1.985E-05	3.247E-05	2.339E-05	1.862E+04	2.756E+04
Am246	8.047E-02	1.141E-01	1.978E-01	4.247E-02	5.363E-03	1.433E-03	4.173E-02	6.000E-02	4.714E-02	9.099E+00	1.256E+01
At217	3.804E-04	4.193E-04	8.267E-04	1.943E-04	2.542E-05	6.913E-06	1.899E-04	2.088E-04	1.985E-04	2.177E+03	2.604E+03
Au198	1.215E-02	1.835E-02	2.907E-02	6.125E-03	7.472E-04	2.008E-04	6.009E-03	9.164E-03	6.930E-03	6.192E+01	8.964E+01
Ba133	2.421E-03	3.908E-03	5.653E-03	1.171E-03	1.417E-04	3.820E-05	1.156E-03	1.886E-03	1.359E-03	3.184E+02	4.712E+02
Ba137m	4.704E-02	6.813E-02	1.145E-01	2.434E-02	3.023E-03	8.090E-04	2.395E-02	3.513E-02	2.719E-02	1.572E+01	2.225E+01
Ba140	8.066E-03	1.200E-02	1.946E-02	4.111E-03	5.061E-04	1.350E-04	4.027E-03	6.053E-03	4.621E-03	9.248E+01	1.333E+02
Be10	2.822E-06	4.548E-06	6.588E-06	1.366E-06	1.653E-07	4.441E-08	1.347E-06	2.194E-06	1.586E-06	2.732E+05	4.053E+05
Bi207	6.505E-01	8.588E-01	1.650E+00	3.695E-01	4.816E-02	1.322E-02	3.729E-01	4.946E-01	4.079E-01	1.091E+00	1.362E+00
Bi210	1.266E-04	1.865E-04	3.069E-04	6.523E-05	8.118E-06	2.172E-06	6.415E-05	9.538E-05	7.326E-05	5.865E+03	8.287E+03
Bi211	7.137E-04	9.623E-04	1.605E-03	3.550E-04	4.481E-05	1.214E-05	3.485E-04	4.703E-04	3.857E-04	1.121E+03	1.483E+03
Bi212	6.025E-02	7.789E-02	1.537E-01	3.487E-02	4.625E-03	1.270E-03	3.574E-02	4.607E-02	3.867E-02	1.171E+01	1.417E+01
Bi213	6.177E-03	8.858E-03	1.514E-02	3.265E-03	4.094E-04	1.109E-04	3.229E-03	4.660E-03	3.647E-03	1.189E+02	1.624E+02
Bi214	1.453E+00	1.840E+00	3.734E+00	8.598E-01	1.152E-01	3.154E-02	8.892E-01	1.123E+00	9.554E-01	4.821E-01	5.707E-01
Bk247	7.983E-05	1.394E-04	1.798E-04	3.668E-05	4.417E-06	1.178E-06	3.662E-05	6.483E-05	4.432E-05	1.001E+04	1.528E+04
Bk249	1.586E-05	1.733E-05	3.466E-05	8.178E-06	1.073E-06	2.931E-07	8.098E-06	8.803E-06	8.455E-06	5.193E+04	6.142E+04
Bk250	3.968E-01	5.323E-01	1.000E+00	2.213E-01	2.867E-02	7.804E-03	2.210E-01	2.991E-01	2.438E-01	1.800E+00	2.307E+00
C14	7.567E-11	1.585E-10	1.574E-10	3.167E-11	3.822E-12	9.922E-13	3.284E-11	7.020E-11	4.256E-11	1.136E+10	1.814E+10
Ca45	4.282E-09	7.852E-09	9.462E-09	1.925E-09	2.320E-10	6.149E-11	1.939E-09	3.604E-09	2.386E-09	1.902E+08	2.927E+08
Cd113	4.421E-08	7.554E-08	1.007E-07	2.067E-08	2.495E-09	6.678E-10	2.057E-08	3.555E-08	2.468E-08	1.787E+07	2.695E+07

Table 7.5-1 – Bare Cask Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Cd113m	3.120E-06	5.013E-06	7.291E-06	1.513E-06	1.831E-07	4.918E-08	1.492E-06	2.422E-06	1.754E-06	2.469E+05	3.660E+05
Cd115m	1.587E-02	2.122E-02	4.002E-02	8.889E-03	1.165E-03	3.138E-04	8.896E-03	1.198E-02	9.801E-03	4.498E+01	5.736E+01
Ce141	1.826E-06	3.275E-06	4.087E-06	8.385E-07	1.014E-07	2.692E-08	8.417E-07	1.523E-06	1.026E-06	4.404E+05	6.686E+05
Ce144	1.811E-07	3.691E-07	3.820E-07	7.710E-08	9.306E-09	2.428E-09	7.944E-08	1.648E-07	1.018E-07	4.712E+06	7.414E+06
Cf249	2.606E-03	3.991E-03	6.021E-03	1.273E-03	1.562E-04	4.218E-05	1.255E-03	1.936E-03	1.449E-03	2.990E+02	4.267E+02
Cf250	2.342E+01	2.557E+01	5.139E+01	1.215E+01	1.598E+00	4.354E-01	1.209E+01	1.311E+01	1.261E+01	3.503E-02	4.134E-02
Cf251	2.819E-04	3.264E-04	6.125E-04	1.424E-04	1.852E-05	5.037E-06	1.393E-04	1.606E-04	1.475E-04	2.939E+03	3.573E+03
Cf252	1.085E+03	1.186E+03	2.370E+03	5.589E+02	7.331E+01	2.003E+01	5.533E+02	6.014E+02	5.775E+02	7.595E-04	8.986E-04
Cf253	8.907E-07	9.827E-07	1.929E-06	4.537E-07	5.937E-08	1.616E-08	4.431E-07	4.875E-07	4.633E-07	9.333E+05	1.114E+06
Cf254	3.341E+04	3.648E+04	7.331E+04	1.733E+04	2.280E+03	6.211E+02	1.725E+04	1.871E+04	1.799E+04	2.455E-05	2.898E-05
Cl36	1.893E-05	2.892E-05	4.516E-05	9.482E-06	1.160E-06	3.104E-07	9.308E-06	1.437E-05	1.077E-05	3.986E+04	5.800E+04
Cm240	1.202E-03	1.313E-03	2.618E-03	6.173E-04	8.092E-05	2.209E-05	6.088E-04	6.622E-04	6.353E-04	6.875E+02	8.148E+02
Cm242	1.787E-03	1.954E-03	3.900E-03	9.199E-04	1.207E-04	3.294E-05	9.088E-04	9.886E-04	9.488E-04	4.616E+02	5.464E+02
Cm243	3.362E-04	4.186E-04	7.344E-04	1.676E-04	2.157E-05	5.852E-06	1.644E-04	2.037E-04	1.775E-04	2.451E+03	3.076E+03
Cm244	3.442E-02	3.761E-02	7.521E-02	1.774E-02	2.328E-03	6.359E-04	1.757E-02	1.910E-02	1.834E-02	2.393E+01	2.831E+01
Cm245	3.552E-04	3.892E-04	7.716E-04	1.819E-04	2.384E-05	6.510E-06	1.788E-04	1.951E-04	1.867E-04	2.333E+03	2.765E+03
Cm246	7.734E+00	8.451E+00	1.690E+01	3.988E+00	5.233E-01	1.429E-01	3.949E+00	4.293E+00	4.123E+00	1.065E-01	1.260E-01
Cm247	8.181E-03	1.246E-02	1.941E-02	4.072E-03	4.937E-04	1.325E-04	3.987E-03	6.141E-03	4.617E-03	9.273E+01	1.359E+02
Cm248	2.402E+03	2.625E+03	5.252E+03	1.239E+03	1.627E+02	4.442E+01	1.228E+03	1.335E+03	1.282E+03	3.428E-04	4.052E-04
Cm249	1.288E-03	1.879E-03	3.128E-03	6.637E-04	8.226E-05	2.200E-05	6.524E-04	9.633E-04	7.426E-04	5.755E+02	8.182E+02
Cm250	1.416E+01	1.743E+01	3.666E+01	8.660E+00	1.183E+00	3.265E-01	9.081E+00	1.118E+01	9.693E+00	4.910E-02	5.514E-02
Co57	1.085E-04	1.567E-04	2.641E-04	5.630E-05	7.041E-06	1.884E-06	5.526E-05	8.111E-05	6.282E-05	6.815E+03	9.555E+03
Co58	2.193E-01	3.026E-01	5.462E-01	1.188E-01	1.520E-02	4.088E-03	1.176E-01	1.640E-01	1.314E-01	3.296E+00	4.403E+00
Co60	1.530E+00	2.018E+00	3.883E+00	8.703E-01	1.142E-01	3.101E-02	8.738E-01	1.162E+00	9.578E-01	4.635E-01	5.804E-01
Cr51	2.664E-04	4.297E-04	6.222E-04	1.289E-04	1.560E-05	4.205E-06	1.272E-04	2.074E-04	1.496E-04	2.893E+03	4.281E+03
Cs134	2.345E-01	3.263E-01	5.819E-01	1.265E-01	1.617E-02	4.328E-03	1.254E-01	1.758E-01	1.403E-01	3.093E+00	4.159E+00
Cs135	3.374E-10	7.050E-10	7.026E-10	1.414E-10	1.707E-11	4.432E-12	1.466E-10	3.125E-10	1.897E-10	2.553E+09	4.061E+09
Cs137	9.383E-06	1.398E-05	2.264E-05	4.799E-06	5.957E-07	1.595E-07	4.723E-06	7.099E-06	5.412E-06	7.951E+04	1.129E+05
Cu64	1.708E-02	2.409E-02	4.217E-02	9.167E-03	1.164E-03	3.125E-04	9.122E-03	1.291E-02	1.023E-02	4.268E+01	5.759E+01
Dy159	2.752E-08	4.446E-08	6.425E-08	1.331E-08	1.610E-09	4.340E-10	1.313E-08	2.145E-08	1.545E-08	2.802E+07	4.148E+07
Es252	3.042E-02	4.252E-02	7.542E-02	1.632E-02	2.088E-03	5.555E-04	1.607E-02	2.268E-02	1.805E-02	2.387E+01	3.240E+01

Table 7.5-1 – Bare Cask Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Es253	3.387E-03	3.700E-03	7.422E-03	1.753E-03	2.306E-04	6.281E-05	1.742E-03	1.891E-03	1.817E-03	2.425E+02	2.866E+02
Es254	1.385E-03	1.516E-03	3.030E-03	7.152E-04	9.396E-05	2.559E-05	7.085E-04	7.710E-04	7.395E-04	5.940E+02	7.034E+02
Es254m	1.532E+01	1.674E+01	3.364E+01	7.950E+00	1.046E+00	2.850E-01	7.913E+00	8.586E+00	8.257E+00	5.351E-02	6.316E-02
Eu149	4.807E-04	7.307E-04	1.150E-03	2.419E-04	2.967E-05	7.933E-06	2.374E-04	3.645E-04	2.741E-04	1.565E+03	2.269E+03
Eu150	2.621E-01	3.518E-01	6.601E-01	1.468E-01	1.909E-02	5.179E-03	1.475E-01	1.988E-01	1.625E-01	2.727E+00	3.476E+00
Eu152	5.677E-01	7.464E-01	1.441E+00	3.233E-01	4.239E-02	1.151E-02	3.262E-01	4.316E-01	3.569E-01	1.249E+00	1.564E+00
Eu154	5.937E-01	7.856E-01	1.504E+00	3.364E-01	4.416E-02	1.196E-02	3.381E-01	4.502E-01	3.708E-01	1.197E+00	1.505E+00
Eu155	2.947E-07	6.170E-07	6.129E-07	1.233E-07	1.489E-08	3.864E-09	1.279E-07	2.734E-07	1.657E-07	2.917E+06	4.658E+06
Fe55	1.779E-15	3.725E-15	3.699E-15	7.445E-16	8.985E-17	2.332E-17	7.721E-16	1.650E-15	1.000E-15	4.832E+14	7.717E+14
Fe59	7.443E-01	9.825E-01	1.888E+00	4.229E-01	5.539E-02	1.506E-02	4.244E-01	5.649E-01	4.654E-01	9.533E-01	1.195E+00
Fr221	3.923E-04	4.586E-04	8.575E-04	1.985E-04	2.575E-05	6.992E-06	1.942E-04	2.263E-04	2.062E-04	2.099E+03	2.574E+03
Fr223	1.515E-03	2.133E-03	3.746E-03	8.086E-04	1.029E-04	2.746E-05	7.961E-04	1.132E-03	8.964E-04	4.805E+02	6.556E+02
Gd152	1.728E-07	1.901E-07	3.891E-07	9.163E-08	1.217E-08	3.304E-09	9.399E-08	1.024E-07	9.730E-08	4.626E+06	5.448E+06
Gd153	2.939E-07	6.154E-07	6.112E-07	1.230E-07	1.485E-08	3.854E-09	1.276E-07	2.727E-07	1.653E-07	2.925E+06	4.671E+06
Hf175	2.430E-03	3.906E-03	5.682E-03	1.178E-03	1.425E-04	3.841E-05	1.162E-03	1.888E-03	1.365E-03	3.168E+02	4.686E+02
Hf181	9.551E-03	1.464E-02	2.269E-02	4.750E-03	5.752E-04	1.543E-04	4.652E-03	7.211E-03	5.398E-03	7.933E+01	1.167E+02
Hg203	2.162E-04	3.771E-04	4.870E-04	9.937E-05	1.197E-05	3.192E-06	9.918E-05	1.754E-04	1.200E-04	3.696E+03	5.639E+03
Ho166m	2.621E-01	3.633E-01	6.518E-01	1.416E-01	1.813E-02	4.853E-03	1.399E-01	1.960E-01	1.567E-01	2.762E+00	3.709E+00
I129	3.806E-11	7.971E-11	7.916E-11	1.593E-11	1.923E-12	4.991E-13	1.652E-11	3.531E-11	2.141E-11	2.258E+10	3.607E+10
I131	8.291E-03	1.230E-02	2.004E-02	4.247E-03	5.277E-04	1.411E-04	4.180E-03	6.259E-03	4.780E-03	8.982E+01	1.276E+02
In113m	1.733E-03	2.796E-03	4.048E-03	8.386E-04	1.015E-04	2.736E-05	8.274E-04	1.349E-03	9.731E-04	4.447E+02	6.579E+02
In114	3.429E-03	4.647E-03	8.602E-03	1.903E-03	2.471E-04	6.668E-05	1.901E-03	2.592E-03	2.104E-03	2.092E+02	2.699E+02
In114m	4.822E-03	6.865E-03	1.187E-02	2.549E-03	3.229E-04	8.568E-05	2.502E-03	3.596E-03	2.830E-03	1.517E+02	2.101E+02
In115	1.064E-06	1.737E-06	2.470E-06	5.109E-07	6.177E-08	1.660E-08	5.049E-07	8.332E-07	5.965E-07	7.286E+05	1.085E+06
In115m	1.236E-03	1.993E-03	2.887E-03	5.981E-04	7.239E-05	1.951E-05	5.902E-04	9.622E-04	6.940E-04	6.235E+02	9.225E+02
Ir194	2.290E-02	3.029E-02	5.798E-02	1.299E-02	1.701E-03	4.642E-04	1.314E-02	1.743E-02	1.438E-02	3.105E+01	3.877E+01
K40	1.428E-01	1.844E-01	3.648E-01	8.272E-02	1.096E-02	2.968E-03	8.422E-02	1.093E-01	9.147E-02	4.934E+00	6.064E+00
K42	4.546E-01	5.750E-01	1.168E+00	2.682E-01	3.591E-02	9.913E-03	2.778E-01	3.501E-01	2.978E-01	1.541E+00	1.816E+00
Kr85	1.422E-04	2.117E-04	3.430E-04	7.245E-05	8.921E-06	2.380E-06	7.098E-05	1.068E-04	8.146E-05	5.248E+03	7.563E+03
La140	2.652E+00	3.346E+00	6.819E+00	1.571E+00	2.106E-01	5.815E-02	1.628E+00	2.048E+00	1.746E+00	2.640E-01	3.095E-01
Lu177	3.456E-05	5.948E-05	7.837E-05	1.604E-05	1.933E-06	5.166E-07	1.597E-05	2.785E-05	1.922E-05	2.297E+04	3.484E+04

Table 7.5-1 – Bare Cask Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Lu177m	2.396E-03	3.697E-03	5.680E-03	1.188E-03	1.439E-04	3.861E-05	1.164E-03	1.817E-03	1.353E-03	3.169E+02	4.662E+02
Mn54	1.979E-01	2.735E-01	4.925E-01	1.069E-01	1.366E-02	3.666E-03	1.055E-01	1.477E-01	1.181E-01	3.655E+00	4.910E+00
Na22	9.694E-01	1.281E+00	2.457E+00	5.511E-01	7.269E-02	1.961E-02	5.538E-01	7.363E-01	6.073E-01	7.326E-01	9.179E-01
Na24	8.997E+00	1.104E+01	2.334E+01	5.520E+00	7.507E-01	2.084E-01	5.788E+00	7.118E+00	6.180E+00	7.712E-02	8.637E-02
Nb91	9.445E-05	1.400E-04	2.283E-04	4.827E-05	5.950E-06	1.587E-06	4.728E-05	7.081E-05	5.418E-05	7.884E+03	1.134E+04
Nb94	3.161E-01	4.401E-01	7.849E-01	1.699E-01	2.169E-02	5.797E-03	1.674E-01	2.358E-01	1.879E-01	2.293E+00	3.105E+00
Nb95	1.184E-01	1.669E-01	2.928E-01	6.314E-02	8.048E-03	2.133E-03	6.200E-02	8.819E-02	6.989E-02	6.148E+00	8.437E+00
Nb95m	1.029E-04	1.701E-04	2.378E-04	4.926E-05	6.015E-06	1.603E-06	4.888E-05	8.150E-05	5.797E-05	7.569E+03	1.123E+04
Nd144	4.453E-08	5.129E-08	1.059E-07	2.493E-08	3.343E-09	9.109E-10	2.564E-08	2.946E-08	2.692E-08	1.699E+07	1.976E+07
Ni59	2.226E-08	3.298E-08	5.380E-08	1.138E-08	1.402E-09	3.740E-10	1.114E-08	1.669E-08	1.277E-08	3.345E+07	4.813E+07
Np235	9.823E-09	1.666E-08	2.075E-08	4.468E-09	5.597E-10	1.490E-10	4.514E-09	7.608E-09	5.357E-09	8.675E+07	1.208E+08
Np237	1.233E-04	1.355E-04	2.664E-04	6.277E-05	8.207E-06	2.249E-06	6.137E-05	6.723E-05	6.411E-05	6.756E+03	8.005E+03
Np238	2.599E-01	3.488E-01	6.551E-01	1.450E-01	1.878E-02	5.111E-03	1.447E-01	1.960E-01	1.597E-01	2.748E+00	3.522E+00
Np239	1.853E-04	3.097E-04	4.261E-04	8.771E-05	1.059E-05	2.842E-06	8.697E-05	1.470E-04	1.036E-04	4.224E+03	6.334E+03
Np240	2.216E-01	3.043E-01	5.528E-01	1.207E-01	1.553E-02	4.179E-03	1.197E-01	1.659E-01	1.333E-01	3.256E+00	4.307E+00
Np240m	8.620E-02	1.138E-01	2.182E-01	4.895E-02	6.428E-03	1.749E-03	4.970E-02	6.564E-02	5.428E-02	8.249E+00	1.029E+01
Os185	6.874E-02	9.787E-02	1.687E-01	3.615E-02	4.543E-03	1.216E-03	3.561E-02	5.131E-02	4.021E-02	1.067E+01	1.480E+01
Os194	1.607E-17	3.365E-17	3.342E-17	6.726E-18	8.118E-19	2.107E-19	6.975E-18	1.491E-17	9.038E-18	5.349E+16	8.542E+16
P32	1.180E-03	1.655E-03	2.918E-03	6.335E-04	8.066E-05	2.171E-05	6.276E-04	8.871E-04	7.037E-04	6.168E+02	8.292E+02
P33	3.159E-09	5.871E-09	6.938E-09	1.410E-09	1.699E-10	4.495E-11	1.424E-09	2.684E-09	1.761E-09	2.594E+08	4.005E+08
Pa231	3.603E-04	5.068E-04	8.172E-04	1.782E-04	2.228E-05	6.044E-06	1.751E-04	2.469E-04	1.964E-04	2.203E+03	2.978E+03
Pa233	1.590E-03	2.548E-03	3.721E-03	7.719E-04	9.342E-05	2.517E-05	7.609E-04	1.233E-03	8.933E-04	4.837E+02	7.153E+02
Pa234	4.659E-01	6.202E-01	1.176E+00	2.618E-01	3.427E-02	9.296E-03	2.639E-01	3.525E-01	2.897E-01	1.531E+00	1.936E+00
Pa234m	1.279E-02	1.695E-02	3.239E-02	7.247E-03	9.463E-04	2.593E-04	7.312E-03	9.723E-03	8.010E-03	5.557E+01	6.943E+01
Pb209	4.802E-06	7.619E-06	1.128E-05	2.347E-06	2.846E-07	7.640E-08	2.311E-06	3.704E-06	2.706E-06	1.596E+05	2.356E+05
Pb210	5.657E-13	6.203E-13	1.233E-12	2.910E-13	3.801E-14	1.046E-14	2.874E-13	3.152E-13	3.031E-13	1.460E+12	1.721E+12
Pb211	1.033E-02	1.436E-02	2.564E-02	5.562E-03	7.093E-04	1.905E-04	5.493E-03	7.723E-03	6.157E-03	7.020E+01	9.448E+01
Pb212	2.060E-04	3.474E-04	4.717E-04	9.691E-05	1.170E-05	3.135E-06	9.622E-05	1.642E-04	1.149E-04	3.816E+03	5.742E+03
Pb214	3.758E-03	5.512E-03	9.140E-03	1.950E-03	2.448E-04	6.546E-05	1.921E-03	2.840E-03	2.189E-03	1.969E+02	2.750E+02
Pm145	5.218E-17	6.470E-17	1.349E-16	3.168E-17	4.309E-18	1.187E-18	3.311E-17	4.102E-17	3.542E-17	1.334E+16	1.516E+16
Pm146	7.548E-02	1.073E-01	1.859E-01	3.997E-02	5.070E-03	1.345E-03	3.924E-02	5.629E-02	4.435E-02	9.683E+00	1.338E+01

Table 7.5-1 – Bare Cask Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Pm147	7.943E-10	1.585E-09	1.691E-09	3.416E-10	4.121E-11	1.079E-11	3.503E-10	7.109E-10	4.451E-10	1.065E+09	1.669E+09
Pm148	3.498E-01	4.556E-01	8.904E-01	2.009E-01	2.652E-02	7.177E-03	2.039E-01	2.668E-01	2.222E-01	2.022E+00	2.508E+00
Pm148m	3.040E-01	4.207E-01	7.564E-01	1.650E-01	2.107E-02	5.695E-03	1.637E-01	2.285E-01	1.827E-01	2.380E+00	3.161E+00
Po209	9.315E-04	1.288E-03	2.318E-03	5.030E-04	6.428E-05	1.725E-05	4.965E-04	6.954E-04	5.559E-04	7.765E+02	1.043E+03
Po210	1.876E-04	2.058E-04	4.063E-04	9.572E-05	1.253E-05	3.422E-06	9.351E-05	1.023E-04	9.763E-05	4.430E+03	5.260E+03
Po211	1.627E-03	2.158E-03	3.918E-03	8.632E-04	1.105E-04	2.975E-05	8.496E-04	1.140E-03	9.391E-04	4.594E+02	6.051E+02
Po212	3.709E-04	4.056E-04	8.034E-04	1.893E-04	2.479E-05	6.747E-06	1.850E-04	2.017E-04	1.930E-04	2.241E+03	2.668E+03
Po213	3.766E-04	4.136E-04	8.175E-04	1.924E-04	2.518E-05	6.849E-06	1.880E-04	2.059E-04	1.963E-04	2.202E+03	2.628E+03
Po214	3.832E-04	4.229E-04	8.337E-04	1.959E-04	2.563E-05	6.968E-06	1.914E-04	2.108E-04	2.002E-04	2.159E+03	2.583E+03
Po215	3.834E-04	4.239E-04	8.336E-04	1.957E-04	2.559E-05	6.960E-06	1.913E-04	2.110E-04	2.002E-04	2.159E+03	2.586E+03
Po216	3.747E-04	4.108E-04	8.127E-04	1.914E-04	2.505E-05	6.816E-06	1.870E-04	2.045E-04	1.952E-04	2.215E+03	2.641E+03
Po218	2.882E-04	3.158E-04	6.244E-04	1.471E-04	1.926E-05	5.245E-06	1.436E-04	1.570E-04	1.499E-04	2.883E+03	3.432E+03
Pr143	4.304E-05	6.511E-05	1.031E-04	2.172E-05	2.671E-06	7.149E-07	2.134E-05	3.260E-05	2.460E-05	1.746E+04	2.518E+04
Pr144	5.557E-02	7.007E-02	1.431E-01	3.318E-02	4.466E-03	1.211E-03	3.446E-02	4.321E-02	3.698E-02	1.258E+01	1.486E+01
Pr144m	1.455E-03	1.849E-03	3.735E-03	8.561E-04	1.145E-04	3.174E-05	8.850E-04	1.120E-03	9.509E-04	4.820E+02	5.670E+02
Pu236	2.753E-04	3.011E-04	5.961E-04	1.405E-04	1.841E-05	5.018E-06	1.374E-04	1.499E-04	1.433E-04	3.020E+03	3.587E+03
Pu238	2.487E-04	2.720E-04	5.387E-04	1.270E-04	1.665E-05	4.542E-06	1.243E-04	1.356E-04	1.297E-04	3.341E+03	3.963E+03
Pu239	1.644E-04	1.801E-04	3.556E-04	8.383E-05	1.097E-05	3.000E-06	8.189E-05	8.941E-05	8.545E-05	5.062E+03	5.999E+03
Pu240	1.308E-03	1.430E-03	2.857E-03	6.741E-04	8.847E-05	2.416E-05	6.668E-04	7.252E-04	6.962E-04	6.301E+02	7.451E+02
Pu241	3.430E-09	3.761E-09	7.411E-09	1.747E-09	2.286E-10	6.260E-11	1.708E-09	1.866E-09	1.783E-09	2.429E+08	2.876E+08
Pu242	1.098E-01	1.200E-01	2.401E-01	5.667E-02	7.439E-03	2.031E-03	5.614E-02	6.104E-02	5.863E-02	7.496E+00	8.863E+00
Pu243	2.383E-05	3.831E-05	5.572E-05	1.155E-05	1.398E-06	3.767E-07	1.139E-05	1.851E-05	1.339E-05	3.230E+04	4.779E+04
Pu244	2.542E+01	2.777E+01	5.561E+01	1.313E+01	1.724E+00	4.706E-01	1.302E+01	1.415E+01	1.360E+01	3.237E-02	3.825E-02
Pu246	6.421E-05	1.123E-04	1.445E-04	2.948E-05	3.550E-06	9.470E-07	2.944E-05	5.220E-05	3.565E-05	1.245E+04	1.901E+04
Ra223	7.385E-04	1.046E-03	1.696E-03	3.677E-04	4.584E-05	1.237E-05	3.609E-04	5.138E-04	4.065E-04	1.061E+03	1.455E+03
Ra224	2.505E-04	2.823E-04	5.437E-04	1.272E-04	1.660E-05	4.520E-06	1.243E-04	1.397E-04	1.307E-04	3.311E+03	3.983E+03
Ra225	6.190E-08	1.049E-07	1.415E-07	2.908E-08	3.511E-09	9.405E-10	2.890E-08	4.954E-08	3.457E-08	1.272E+07	1.914E+07
Ra226	1.294E-04	1.417E-04	2.796E-04	6.592E-05	8.622E-06	2.363E-06	6.445E-05	7.037E-05	6.727E-05	6.438E+03	7.619E+03
Rb86	5.466E-02	7.278E-02	1.383E-01	3.079E-02	3.982E-03	1.092E-03	3.080E-02	4.140E-02	3.388E-02	1.301E+01	1.648E+01
Rb87	7.974E-09	1.423E-08	1.782E-08	3.637E-09	4.384E-10	1.167E-10	3.646E-09	6.591E-09	4.443E-09	1.010E+08	1.543E+08
Re188	1.403E-02	1.859E-02	3.550E-02	7.948E-03	1.043E-03	2.849E-04	8.052E-03	1.067E-02	8.808E-03	5.070E+01	6.318E+01

Table 7.5-1 – Bare Cask Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Rh102	5.580E-02	7.655E-02	1.394E-01	3.069E-02	3.937E-03	1.070E-03	3.070E-02	4.227E-02	3.406E-02	1.292E+01	1.682E+01
Rh106	6.684E-02	8.856E-02	1.691E-01	3.801E-02	4.980E-03	1.358E-03	3.861E-02	5.110E-02	4.222E-02	1.064E+01	1.325E+01
Rn219	1.166E-03	1.625E-03	2.692E-03	5.847E-04	7.271E-05	1.959E-05	5.723E-04	8.027E-04	6.426E-04	6.687E+02	9.186E+02
Rn220	3.686E-04	4.163E-04	8.066E-04	1.881E-04	2.450E-05	6.656E-06	1.838E-04	2.074E-04	1.935E-04	2.232E+03	2.704E+03
Rn222	2.337E-04	2.644E-04	5.111E-04	1.192E-04	1.552E-05	4.225E-06	1.164E-04	1.317E-04	1.226E-04	3.522E+03	4.260E+03
Ru103	1.346E-02	2.033E-02	3.218E-02	6.762E-03	8.238E-04	2.208E-04	6.627E-03	1.013E-02	7.648E-03	5.594E+01	8.152E+01
S35	1.113E-10	2.330E-10	2.315E-10	4.658E-11	5.622E-12	1.459E-12	4.830E-11	1.032E-10	6.259E-11	7.724E+09	1.234E+10
Sb124	1.635E+00	2.072E+00	4.198E+00	9.651E-01	1.292E-01	3.547E-02	9.994E-01	1.261E+00	1.073E+00	4.288E-01	5.075E-01
Sb125	2.343E-02	3.430E-02	5.678E-02	1.204E-02	1.488E-03	3.985E-04	1.183E-02	1.753E-02	1.349E-02	3.170E+01	4.517E+01
Sb126	3.182E-01	4.484E-01	7.845E-01	1.693E-01	2.147E-02	5.750E-03	1.670E-01	2.380E-01	1.879E-01	2.294E+00	3.130E+00
Sb126m	1.320E-01	1.885E-01	3.233E-01	6.933E-02	8.697E-03	2.337E-03	6.837E-02	9.881E-02	7.723E-02	5.568E+00	7.702E+00
Sc46	8.140E-01	1.093E+00	2.052E+00	4.543E-01	5.861E-02	1.600E-02	4.532E-01	6.145E-01	5.003E-01	8.770E-01	1.125E+00
Se75	1.546E-03	2.415E-03	3.645E-03	7.604E-04	9.200E-05	2.466E-05	7.465E-04	1.179E-03	8.714E-04	4.938E+02	7.300E+02
Se79	1.301E-10	2.725E-10	2.706E-10	5.445E-11	6.573E-12	1.706E-12	5.647E-11	1.207E-10	7.318E-11	6.606E+09	1.055E+10
Sm145	3.697E-07	5.657E-07	8.787E-07	1.840E-07	2.227E-08	5.973E-09	1.801E-07	2.788E-07	2.090E-07	2.048E+06	3.014E+06
Sm146	8.032E-07	8.752E-07	1.776E-06	4.200E-07	5.546E-08	1.513E-08	4.253E-07	4.596E-07	4.420E-07	1.013E+06	1.190E+06
Sm147	3.887E-07	4.241E-07	8.630E-07	2.036E-07	2.695E-08	7.330E-09	2.076E-07	2.241E-07	2.147E-07	2.086E+06	2.456E+06
Sm148	7.102E-08	8.002E-08	1.645E-07	3.876E-08	5.178E-09	1.406E-09	3.969E-08	4.448E-08	4.142E-08	1.094E+07	1.280E+07
Sn113	6.103E-06	1.050E-05	1.384E-05	2.835E-06	3.424E-07	9.137E-08	2.826E-06	4.921E-06	3.400E-06	1.300E+05	1.970E+05
Sn123	4.362E-03	5.848E-03	1.101E-02	2.443E-03	3.154E-04	8.633E-05	2.442E-03	3.302E-03	2.692E-03	1.635E+02	2.085E+02
Sn126	9.115E-08	1.540E-07	2.087E-07	4.290E-08	5.180E-09	1.388E-09	4.261E-08	7.281E-08	5.092E-08	8.625E+06	1.296E+07
Sr85	2.882E-02	4.269E-02	6.965E-02	1.473E-02	1.815E-03	4.841E-04	1.442E-02	2.160E-02	1.653E-02	2.584E+01	3.718E+01
Sr89	6.729E-04	9.557E-04	1.656E-03	3.574E-04	4.523E-05	1.215E-05	3.531E-04	5.056E-04	3.978E-04	1.087E+03	1.481E+03
Sr90	3.089E-06	4.974E-06	7.212E-06	1.496E-06	1.809E-07	4.861E-08	1.475E-06	2.401E-06	1.735E-06	2.496E+05	3.703E+05
Ta182	7.441E-01	9.822E-01	1.888E+00	4.228E-01	5.539E-02	1.506E-02	4.244E-01	5.648E-01	4.654E-01	9.535E-01	1.195E+00
Tb160	3.919E-01	5.263E-01	9.870E-01	2.184E-01	2.840E-02	7.685E-03	2.180E-01	2.954E-01	2.407E-01	1.824E+00	2.342E+00
Tc99	1.830E-08	3.180E-08	4.139E-08	8.475E-09	1.022E-09	2.730E-10	8.457E-09	1.487E-08	1.021E-08	4.349E+07	6.593E+07
Tc99m	1.240E-06	2.595E-06	2.579E-06	5.190E-07	6.264E-08	1.626E-08	5.382E-07	1.150E-06	6.972E-07	6.937E+05	1.107E+06
Te121	2.966E-02	4.396E-02	7.169E-02	1.516E-02	1.868E-03	4.982E-04	1.485E-02	2.224E-02	1.701E-02	2.511E+01	3.613E+01
Te121m	1.635E-02	2.185E-02	4.132E-02	9.188E-03	1.188E-03	3.256E-04	9.192E-03	1.239E-02	1.012E-02	4.357E+01	5.528E+01
Te123m	1.169E-06	2.447E-06	2.431E-06	4.892E-07	5.905E-08	1.533E-08	5.073E-07	1.084E-06	6.573E-07	7.355E+05	1.174E+06

Table 7.5-1 – Bare Cask Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Te125m	3.891E-09	8.148E-09	8.093E-09	1.629E-09	1.966E-10	5.102E-11	1.689E-09	3.610E-09	2.188E-09	2.209E+08	3.528E+08
Te127	1.219E-04	1.872E-04	2.895E-04	6.057E-05	7.334E-06	1.967E-06	5.933E-05	9.216E-05	6.889E-05	6.219E+03	9.150E+03
Te127m	7.335E-06	1.065E-05	1.784E-05	3.791E-06	4.705E-07	1.259E-07	3.728E-06	5.480E-06	4.236E-06	1.009E+05	1.430E+05
Te129	6.668E-03	9.157E-03	1.666E-02	3.660E-03	4.682E-04	1.275E-04	3.643E-03	5.039E-03	4.050E-03	1.081E+02	1.412E+02
Te129m	3.585E-03	5.077E-03	8.817E-03	1.896E-03	2.395E-04	6.411E-05	1.865E-03	2.677E-03	2.105E-03	2.041E+02	2.808E+02
Th227	6.360E-04	9.245E-04	1.449E-03	3.130E-04	3.907E-05	1.055E-05	3.084E-04	4.497E-04	3.496E-04	1.242E+03	1.707E+03
Th228	1.987E-04	2.178E-04	4.298E-04	1.013E-04	1.326E-05	3.620E-06	9.894E-05	1.082E-04	1.033E-04	4.188E+03	4.972E+03
Th229	1.581E-04	1.849E-04	3.446E-04	7.983E-05	1.035E-05	2.826E-06	7.816E-05	9.109E-05	8.299E-05	5.224E+03	6.370E+03
Th230	1.195E-04	1.308E-04	2.582E-04	6.089E-05	7.964E-06	2.183E-06	5.955E-05	6.495E-05	6.214E-05	6.971E+03	8.244E+03
Th231	2.730E-07	4.686E-07	6.208E-07	1.273E-07	1.537E-08	4.110E-09	1.268E-07	2.202E-07	1.524E-07	2.900E+06	4.380E+06
Th232	5.589E-05	6.121E-05	1.211E-04	2.857E-05	3.730E-06	1.026E-06	2.813E-05	3.073E-05	2.949E-05	1.486E+04	1.755E+04
Th234	3.548E-09	7.431E-09	7.380E-09	1.485E-09	1.793E-10	4.653E-11	1.540E-09	3.292E-09	1.996E-09	2.422E+08	3.868E+08
Tl206	9.900E-06	1.368E-05	2.464E-05	5.347E-06	6.832E-07	1.834E-07	5.278E-06	7.390E-06	5.909E-06	7.306E+04	9.814E+04
Tl207	8.863E-04	1.245E-03	2.191E-03	4.735E-04	6.015E-05	1.614E-05	4.672E-04	6.634E-04	5.254E-04	8.214E+02	1.115E+03
Tl208	7.708E+00	9.385E+00	2.004E+01	4.769E+00	6.511E-01	1.814E-01	5.022E+00	6.130E+00	5.350E+00	8.981E-02	9.925E-02
Tl209	2.342E+00	2.961E+00	6.019E+00	1.382E+00	1.851E-01	5.112E-02	1.432E+00	1.804E+00	1.535E+00	2.991E-01	3.521E-01
Tm168	2.159E-01	2.985E-01	5.374E-01	1.169E-01	1.498E-02	4.014E-03	1.156E-01	1.615E-01	1.292E-01	3.349E+00	4.484E+00
Tm170	4.608E-05	6.952E-05	1.105E-04	2.330E-05	2.869E-06	7.677E-07	2.289E-05	3.488E-05	2.636E-05	1.629E+04	2.345E+04
Tm171	1.064E-17	2.228E-17	2.213E-17	4.454E-18	5.376E-19	1.395E-19	4.619E-18	9.873E-18	5.985E-18	8.077E+16	1.290E+17
U232	1.845E-04	2.019E-04	3.990E-04	9.408E-05	1.232E-05	3.365E-06	9.189E-05	1.003E-04	9.587E-05	4.511E+03	5.349E+03
U233	1.326E-04	1.453E-04	2.865E-04	6.754E-05	8.835E-06	2.420E-06	6.602E-05	7.212E-05	6.891E-05	6.282E+03	7.437E+03
U234	1.282E-04	1.403E-04	2.770E-04	6.533E-05	8.546E-06	2.342E-06	6.387E-05	6.965E-05	6.663E-05	6.498E+03	7.686E+03
U235	1.055E-04	1.294E-04	2.302E-04	5.277E-05	6.795E-06	1.857E-06	5.194E-05	6.328E-05	5.585E-05	7.819E+03	9.695E+03
U236	1.144E-04	1.252E-04	2.476E-04	5.840E-05	7.638E-06	2.095E-06	5.733E-05	6.247E-05	5.984E-05	7.269E+03	8.592E+03
U237	9.769E-05	1.655E-04	2.233E-04	4.583E-05	5.530E-06	1.482E-06	4.554E-05	7.807E-05	5.449E-05	8.063E+03	1.215E+04
U238	1.003E-02	1.096E-02	2.196E-02	5.185E-03	6.811E-04	1.859E-04	5.145E-03	5.593E-03	5.374E-03	8.197E+01	9.683E+01
U239	2.027E-03	2.819E-03	5.030E-03	1.090E-03	1.394E-04	3.737E-05	1.078E-03	1.515E-03	1.207E-03	3.578E+02	4.817E+02
U240	2.055E-07	3.549E-07	4.656E-07	9.533E-08	1.150E-08	3.072E-09	9.502E-08	1.662E-07	1.145E-07	3.866E+06	5.859E+06
W181	1.586E-09	3.320E-09	3.298E-09	6.636E-10	8.010E-11	2.079E-11	6.882E-10	1.471E-09	8.918E-10	5.421E+08	8.657E+08
W185	4.105E-07	6.795E-07	9.481E-07	1.956E-07	2.364E-08	6.348E-09	1.937E-07	3.241E-07	2.298E-07	1.898E+06	2.836E+06
W188	1.755E-06	3.058E-06	3.958E-06	8.078E-07	9.728E-08	2.596E-08	8.060E-07	1.424E-06	9.747E-07	4.548E+05	6.934E+05

Table 7.5-1 – Bare Cask Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Xe127	6.515E-04	1.074E-03	1.507E-03	3.111E-04	3.761E-05	1.011E-05	3.079E-04	5.131E-04	3.648E-04	1.194E+03	1.780E+03
Xe131m	2.698E-08	5.651E-08	5.612E-08	1.129E-08	1.363E-09	3.538E-10	1.171E-08	2.503E-08	1.518E-08	3.185E+07	5.087E+07
Y88	3.310E+00	4.173E+00	8.547E+00	1.972E+00	2.655E-01	7.447E-02	2.043E+00	2.563E+00	2.192E+00	2.106E-01	2.417E-01
Y89m	3.025E-01	4.121E-01	7.564E-01	1.655E-01	2.148E-02	5.763E-03	1.645E-01	2.261E-01	1.826E-01	2.380E+00	3.123E+00
Y90	4.971E-03	6.739E-03	1.247E-02	2.757E-03	3.571E-04	9.674E-05	2.762E-03	3.760E-03	3.053E-03	1.444E+02	1.861E+02
Y90m	1.051E-02	1.611E-02	2.495E-02	5.223E-03	6.326E-04	1.696E-04	5.115E-03	7.935E-03	5.938E-03	7.214E+01	1.061E+02
Y91	3.166E-03	4.233E-03	7.986E-03	1.780E-03	2.332E-04	6.290E-05	1.784E-03	2.400E-03	1.964E-03	2.254E+02	2.862E+02
Zn65	3.092E-01	4.114E-01	7.828E-01	1.743E-01	2.255E-02	6.186E-03	1.744E-01	2.343E-01	1.918E-01	2.300E+00	2.910E+00
Zr88	2.615E-03	4.218E-03	6.108E-03	1.265E-03	1.531E-04	4.128E-05	1.249E-03	2.036E-03	1.468E-03	2.947E+02	4.360E+02
Zr90m	5.361E+00	6.598E+00	1.392E+01	3.279E+00	4.465E-01	1.209E-01	3.445E+00	4.211E+00	3.664E+00	1.293E-01	1.488E-01
Zr95	1.170E-01	1.649E-01	2.894E-01	6.241E-02	7.955E-03	2.109E-03	6.128E-02	8.717E-02	6.908E-02	6.220E+00	8.536E+00

Table 7.5-2 – Bare Cask Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Ac225	1.989E-04	2.165E-04	4.142E-04	5.306E-05	9.073E-05	1.011E-04	1.010E-04	1.696E+03
Ac227	1.552E-06	1.687E-06	3.240E-06	4.157E-07	7.077E-07	7.878E-07	7.868E-07	2.165E+05
Ac228	3.550E-02	4.703E-02	4.063E-02	4.637E-03	1.706E-02	2.237E-02	1.986E-02	1.941E+01
Ag108	9.085E-05	1.301E-04	7.868E-05	8.316E-06	3.915E-05	5.544E-05	4.798E-05	1.082E+04
Ag108m	5.967E-03	8.690E-03	4.696E-03	4.808E-04	2.476E-03	3.604E-03	3.073E-03	1.872E+02
Ag110	1.231E-03	1.642E-03	1.399E-03	1.605E-04	5.924E-04	7.797E-04	6.884E-04	5.606E+02
Ag110m	9.865E-02	1.311E-01	1.120E-01	1.274E-02	4.699E-02	6.225E-02	5.496E-02	7.066E+00
Am241	1.634E-04	1.775E-04	3.415E-04	4.378E-05	7.459E-05	8.295E-05	8.293E-05	2.056E+03
Am242	4.057E-08	6.442E-08	2.272E-08	2.209E-09	1.559E-08	2.498E-08	2.062E-08	2.794E+07
Am242m	1.418E-06	1.545E-06	2.992E-06	3.836E-07	6.560E-07	7.302E-07	7.276E-07	2.346E+05
Am243	1.412E-04	1.534E-04	2.951E-04	3.784E-05	6.444E-05	7.168E-05	7.164E-05	2.378E+03
Am245	5.773E-07	9.003E-07	3.600E-07	3.573E-08	2.268E-07	3.553E-07	2.952E-07	1.999E+06
Am246	3.057E-03	4.426E-03	2.454E-03	2.517E-04	1.269E-03	1.850E-03	1.585E-03	3.575E+02
At217	2.896E-04	3.147E-04	6.052E-04	7.752E-05	1.323E-04	1.471E-04	1.472E-04	1.161E+03
Au198	2.735E-04	4.117E-04	1.955E-04	1.998E-05	1.117E-04	1.666E-04	1.417E-04	4.372E+03
Ba133	2.533E-05	4.149E-05	1.221E-05	1.165E-06	9.496E-06	1.578E-05	1.285E-05	4.338E+04
Ba137m	1.411E-03	2.101E-03	1.028E-03	1.035E-04	5.789E-04	8.486E-04	7.271E-04	8.567E+02
Ba140	1.931E-04	2.934E-04	1.292E-04	1.280E-05	7.619E-05	1.181E-04	9.875E-05	6.135E+03
Be10	3.288E-08	5.299E-08	1.722E-08	1.661E-09	1.250E-08	2.034E-08	1.668E-08	3.397E+07
Bi207	5.428E-02	7.293E-02	5.982E-02	6.715E-03	2.574E-02	3.377E-02	3.016E-02	1.340E+01
Bi210	3.783E-06	5.559E-06	2.913E-06	2.984E-07	1.560E-06	2.299E-06	1.957E-06	3.016E+05
Bi211	2.873E-04	3.142E-04	5.951E-04	7.617E-05	1.310E-04	1.463E-04	1.461E-04	1.182E+03
Bi212	6.342E-03	8.279E-03	7.692E-03	8.936E-04	3.130E-03	4.020E-03	3.601E-03	1.007E+02
Bi213	2.710E-04	3.810E-04	2.555E-04	2.760E-05	1.197E-04	1.652E-04	1.449E-04	3.261E+03
Bi214	1.822E-01	2.350E-01	2.325E-01	2.763E-02	9.283E-02	1.183E-01	1.051E-01	3.258E+00
Bk247	3.711E-07	6.614E-07	1.304E-07	1.222E-08	1.343E-07	2.422E-07	1.882E-07	2.721E+06
Bk249	1.247E-05	1.360E-05	2.650E-05	3.397E-06	5.826E-06	6.489E-06	6.451E-06	2.649E+04
Bk250	2.699E-02	3.707E-02	2.711E-02	2.944E-03	1.222E-02	1.652E-02	1.460E-02	3.057E+01
C14	5.527E-14	1.174E-13	9.112E-15	8.389E-16	1.924E-14	4.093E-14	2.837E-14	1.533E+13
Ca45	1.630E-11	2.912E-11	5.768E-12	5.414E-13	5.907E-12	1.067E-11	8.272E-12	6.181E+10
Cd113	3.050E-10	5.160E-10	1.323E-10	1.256E-11	1.129E-10	1.934E-10	1.547E-10	3.488E+09
Cd113m	3.774E-08	6.057E-08	2.016E-08	1.948E-09	1.439E-08	2.332E-08	1.916E-08	2.972E+07
Cd115m	1.152E-03	1.562E-03	1.190E-03	1.309E-04	5.316E-04	7.171E-04	6.257E-04	6.876E+02
Ce141	1.353E-08	2.210E-08	6.863E-09	6.612E-10	5.122E-09	8.441E-09	6.869E-09	8.143E+07
Ce144	2.938E-10	5.464E-10	9.662E-11	9.115E-12	1.062E-10	1.984E-10	1.498E-10	3.294E+09
Cf249	3.434E-04	3.866E-04	6.872E-04	8.776E-05	1.568E-04	1.793E-04	1.761E-04	1.026E+03
Cf250	1.854E+01	2.027E+01	3.980E+01	5.111E+00	8.769E+00	9.776E+00	9.682E+00	1.761E-02
Cf251	1.984E-04	2.156E-04	4.146E-04	5.313E-05	9.058E-05	1.007E-04	1.008E-04	1.694E+03
Cf252	8.514E+02	9.285E+02	1.807E+03	2.315E+02	3.972E+02	4.422E+02	4.400E+02	3.888E-04
Cf253	6.853E-07	7.444E-07	1.433E-06	1.836E-07	3.129E-07	3.479E-07	3.481E-07	4.902E+05
Cf254	2.645E+04	2.892E+04	5.678E+04	7.291E+03	1.251E+04	1.395E+04	1.381E+04	1.234E-05
Cl36	3.738E-07	5.748E-07	2.391E-07	2.358E-08	1.466E-07	2.289E-07	1.909E-07	3.132E+06
Cm240	9.415E-04	1.026E-03	1.990E-03	2.548E-04	4.365E-04	4.858E-04	4.842E-04	3.532E+02
Cm242	1.403E-03	1.530E-03	2.974E-03	3.811E-04	6.530E-04	7.271E-04	7.237E-04	2.361E+02

Table 7.5-2 – Bare Cask Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Cm243	2.018E-04	2.195E-04	4.213E-04	5.399E-05	9.213E-05	1.025E-04	1.025E-04	1.667E+03
Cm244	2.705E-02	2.951E-02	5.747E-02	7.366E-03	1.263E-02	1.407E-02	1.399E-02	1.222E+01
Cm245	2.778E-04	3.024E-04	5.852E-04	7.502E-05	1.282E-04	1.426E-04	1.422E-04	1.200E+03
Cm246	6.081E+00	6.634E+00	1.293E+01	1.657E+00	2.842E+00	3.165E+00	3.146E+00	5.432E-02
Cm247	2.517E-04	3.394E-04	3.178E-04	3.828E-05	1.054E-04	1.417E-04	1.276E-04	2.351E+03
Cm248	1.891E+03	2.063E+03	4.023E+03	5.159E+02	8.847E+02	9.855E+02	9.793E+02	1.745E-04
Cm249	3.662E-05	5.477E-05	2.624E-05	2.633E-06	1.490E-05	2.211E-05	1.884E-05	3.287E+04
Cm250	2.428E+00	3.030E+00	3.504E+00	4.438E-01	1.327E+00	1.647E+00	1.466E+00	2.028E-01
Co57	3.479E-06	5.122E-06	2.618E-06	2.642E-07	1.413E-06	2.099E-06	1.803E-06	3.407E+05
Co58	1.136E-02	1.590E-02	1.045E-02	1.115E-03	4.951E-03	6.971E-03	6.001E-03	8.069E+01
Co60	1.244E-01	1.677E-01	1.327E-01	1.469E-02	5.850E-02	7.754E-02	6.831E-02	6.126E+00
Cr51	2.800E-06	4.585E-06	1.351E-06	1.289E-07	1.050E-06	1.744E-06	1.421E-06	3.926E+05
Cs134	1.195E-02	1.672E-02	1.122E-02	1.209E-03	5.252E-03	7.347E-03	6.359E-03	7.443E+01
Cs135	2.647E-13	5.549E-13	4.769E-14	4.403E-15	9.244E-14	1.941E-13	1.358E-13	3.244E+12
Cs137	2.623E-07	3.867E-07	2.002E-07	2.050E-08	1.080E-07	1.596E-07	1.356E-07	4.390E+06
Cu64	8.985E-04	1.241E-03	9.042E-04	9.984E-05	4.036E-04	5.630E-04	4.871E-04	9.015E+02
Dy159	2.865E-10	4.695E-10	1.379E-10	1.316E-11	1.074E-10	1.785E-10	1.454E-10	3.834E+09
Es252	1.356E-03	1.932E-03	1.152E-03	1.200E-04	5.729E-04	8.220E-04	7.037E-04	7.500E+02
Es253	2.675E-03	2.923E-03	5.726E-03	7.351E-04	1.261E-03	1.405E-03	1.393E-03	1.224E+02
Es254	1.088E-03	1.188E-03	2.321E-03	2.978E-04	5.102E-04	5.684E-04	5.645E-04	3.022E+02
Es254m	1.212E+01	1.326E+01	2.603E+01	3.342E+00	5.736E+00	6.395E+00	6.333E+00	2.693E-02
Eu149	9.959E-06	1.526E-05	6.461E-06	6.383E-07	3.906E-06	6.107E-06	5.089E-06	1.179E+05
Eu150	1.981E-02	2.672E-02	2.135E-02	2.384E-03	9.248E-03	1.238E-02	1.090E-02	3.776E+01
Eu152	4.828E-02	6.479E-02	5.289E-02	5.910E-03	2.251E-02	3.021E-02	2.658E-02	1.523E+01
Eu154	4.778E-02	6.427E-02	5.133E-02	5.715E-03	2.251E-02	2.989E-02	2.627E-02	1.575E+01
Eu155	2.162E-10	4.589E-10	3.588E-11	3.304E-12	7.528E-11	1.600E-10	1.110E-10	3.923E+09
Fe55	1.299E-18	2.759E-18	2.142E-19	1.972E-20	4.522E-19	9.621E-19	6.670E-19	6.523E+17
Fe59	5.991E-02	8.089E-02	6.370E-02	7.046E-03	2.812E-02	3.728E-02	3.288E-02	1.277E+01
Fr221	2.646E-04	2.878E-04	5.524E-04	7.076E-05	1.208E-04	1.344E-04	1.345E-04	1.272E+03
Fr223	6.480E-05	9.258E-05	5.461E-05	5.674E-06	2.733E-05	3.935E-05	3.361E-05	1.586E+04
Gd152	1.267E-07	1.387E-07	2.748E-07	3.511E-08	6.188E-08	6.882E-08	6.776E-08	2.564E+06
Gd153	2.146E-10	4.559E-10	3.539E-11	3.258E-12	7.471E-11	1.590E-10	1.102E-10	3.948E+09
Hf175	2.661E-05	4.336E-05	1.312E-05	1.255E-06	1.001E-05	1.653E-05	1.350E-05	4.151E+04
Hf181	1.638E-04	2.560E-04	9.601E-05	9.352E-06	6.359E-05	9.968E-05	8.305E-05	7.031E+03
Hg203	1.008E-06	1.797E-06	3.543E-07	3.320E-08	3.648E-07	6.580E-07	5.113E-07	1.002E+06
Ho166m	1.306E-02	1.836E-02	1.179E-02	1.250E-03	5.648E-03	7.992E-03	6.867E-03	7.197E+01
I129	2.780E-14	5.905E-14	4.583E-15	4.220E-16	9.676E-15	2.059E-14	1.427E-14	3.049E+13
I131	2.271E-04	3.376E-04	1.668E-04	1.690E-05	9.292E-05	1.374E-04	1.168E-04	5.326E+03
In113m	1.822E-05	2.983E-05	8.789E-06	8.386E-07	6.830E-06	1.135E-05	9.245E-06	6.034E+04
In114	2.341E-04	3.184E-04	2.421E-04	2.670E-05	1.083E-04	1.458E-04	1.275E-04	3.370E+03
In114m	1.805E-04	2.620E-04	1.435E-04	1.472E-05	7.483E-05	1.093E-04	9.291E-05	6.113E+03
In115	1.087E-08	1.774E-08	5.397E-09	5.176E-10	4.099E-09	6.760E-09	5.513E-09	1.015E+08
In115m	1.303E-05	2.133E-05	6.294E-06	6.007E-07	4.886E-06	8.112E-06	6.611E-06	8.440E+04
Ir194	1.963E-03	2.617E-03	2.211E-03	2.509E-04	9.363E-04	1.234E-03	1.094E-03	3.588E+02

Table 7.5-2 – Bare Cask Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
K40	1.415E-02	1.876E-02	1.620E-02	1.834E-03	6.678E-03	8.959E-03	7.855E-03	4.909E+01
K42	5.473E-02	7.092E-02	6.786E-02	7.933E-03	2.747E-02	3.500E-02	3.141E-02	1.134E+01
Kr85	3.403E-06	5.167E-06	2.280E-06	2.259E-07	1.342E-06	2.081E-06	1.740E-06	3.483E+05
La140	3.336E-01	4.300E-01	4.234E-01	5.009E-02	1.696E-01	2.151E-01	1.929E-01	1.797E+00
Lu177	1.985E-07	3.439E-07	7.875E-08	7.437E-09	7.273E-08	1.275E-07	1.007E-07	5.234E+06
Lu177m	3.943E-05	6.175E-05	2.300E-05	2.243E-06	1.529E-05	2.405E-05	2.001E-05	2.915E+04
Mn54	9.664E-03	1.364E-02	8.482E-03	8.880E-04	4.124E-03	5.892E-03	5.042E-03	1.014E+02
Na22	8.013E-02	1.074E-01	8.644E-02	9.629E-03	3.804E-02	5.042E-02	4.408E-02	9.346E+00
Na24	1.542E+00	1.930E+00	2.191E+00	2.727E-01	8.340E-01	1.037E+00	9.253E-01	3.301E-01
Nb91	2.330E-06	3.532E-06	1.571E-06	1.558E-07	9.199E-07	1.425E-06	1.192E-06	5.097E+05
Nb94	1.447E-02	2.058E-02	1.239E-02	1.291E-03	6.132E-03	8.799E-03	7.519E-03	6.971E+01
Nb95	4.817E-03	6.944E-03	3.919E-03	4.038E-04	2.011E-03	2.912E-03	2.482E-03	2.229E+02
Nb95m	1.372E-06	2.117E-06	9.138E-07	9.217E-08	5.463E-07	8.480E-07	7.028E-07	8.503E+05
Nd144	2.392E-08	2.672E-08	5.027E-08	6.435E-09	1.179E-08	1.334E-08	1.296E-08	1.399E+07
Ni59	5.490E-10	8.323E-10	3.703E-10	3.671E-11	2.168E-10	3.358E-10	2.808E-10	2.163E+09
Np235	3.069E-09	3.339E-09	6.406E-09	8.219E-10	1.400E-09	1.559E-09	1.556E-09	1.095E+08
Np237	9.582E-05	1.041E-04	2.001E-04	2.569E-05	4.369E-05	4.862E-05	4.856E-05	3.503E+03
Np238	1.764E-02	2.424E-02	1.770E-02	1.920E-03	7.982E-03	1.079E-02	9.541E-03	4.687E+01
Np239	1.493E-06	2.494E-06	6.782E-07	6.458E-08	5.557E-07	9.400E-07	7.573E-07	7.218E+05
Np240	1.210E-02	1.688E-02	1.125E-02	1.198E-03	5.279E-03	7.380E-03	6.407E-03	7.510E+01
Np240m	7.644E-03	1.014E-02	8.764E-03	1.000E-03	3.663E-03	4.833E-03	4.275E-03	8.999E+01
Os185	2.541E-03	3.689E-03	2.034E-03	2.091E-04	1.062E-03	1.538E-03	1.317E-03	4.304E+02
Os194	1.174E-20	2.493E-20	1.935E-21	1.782E-22	4.085E-21	8.692E-21	6.026E-21	7.220E+19
P32	5.812E-05	8.143E-05	5.420E-05	5.812E-06	2.560E-05	3.563E-05	3.097E-05	1.548E+04
P33	1.080E-11	1.946E-11	3.693E-12	3.460E-13	3.901E-12	7.104E-12	5.480E-12	9.250E+10
Pa231	1.136E-04	1.248E-04	2.336E-04	2.994E-05	5.165E-05	5.795E-05	5.762E-05	3.006E+03
Pa233	1.804E-05	2.928E-05	9.052E-06	8.676E-07	6.807E-06	1.118E-05	9.150E-06	6.148E+04
Pa234	3.683E-02	4.935E-02	4.043E-02	4.556E-03	1.730E-02	2.309E-02	2.034E-02	1.975E+01
Pa234m	1.067E-03	1.427E-03	1.190E-03	1.345E-04	5.078E-04	6.675E-04	5.940E-04	6.689E+02
Pb209	6.601E-08	1.047E-07	3.714E-08	3.611E-09	2.538E-08	4.062E-08	3.355E-08	1.720E+07
Pb210	4.505E-13	4.919E-13	9.513E-13	1.227E-13	2.084E-13	2.335E-13	2.313E-13	7.332E+11
Pb211	4.984E-04	7.034E-04	4.433E-04	4.670E-05	2.146E-04	3.039E-04	2.616E-04	1.927E+03
Pb212	1.500E-06	2.532E-06	6.556E-07	6.226E-08	5.556E-07	9.497E-07	7.608E-07	7.109E+05
Pb214	1.248E-04	1.810E-04	1.005E-04	1.038E-05	5.203E-05	7.600E-05	6.457E-05	8.667E+03
Pm145	8.396E-18	1.055E-17	1.186E-17	1.483E-18	4.529E-18	5.648E-18	5.026E-18	6.067E+16
Pm146	2.888E-03	4.179E-03	2.317E-03	2.383E-04	1.202E-03	1.746E-03	1.487E-03	3.777E+02
Pm147	1.461E-12	2.747E-12	4.358E-13	4.072E-14	5.230E-13	9.902E-13	7.436E-13	6.554E+11
Pm148	3.265E-02	4.341E-02	3.692E-02	4.169E-03	1.534E-02	2.062E-02	1.807E-02	2.159E+01
Pm148m	1.629E-02	2.277E-02	1.542E-02	1.655E-03	7.222E-03	9.945E-03	8.721E-03	5.440E+01
Po209	4.545E-05	6.417E-05	3.989E-05	4.176E-06	1.940E-05	2.771E-05	2.371E-05	2.155E+04
Po210	1.453E-04	1.578E-04	3.036E-04	3.893E-05	6.632E-05	7.377E-05	7.372E-05	2.312E+03
Po211	3.468E-04	3.959E-04	6.547E-04	8.269E-05	1.566E-04	1.820E-04	1.771E-04	1.088E+03
Po212	2.892E-04	3.142E-04	6.050E-04	7.749E-05	1.321E-04	1.469E-04	1.471E-04	1.161E+03
Po213	2.895E-04	3.145E-04	6.052E-04	7.751E-05	1.322E-04	1.470E-04	1.472E-04	1.161E+03

Table 7.5-2 – Bare Cask Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Po214	2.897E-04	3.149E-04	6.054E-04	7.753E-05	1.323E-04	1.472E-04	1.473E-04	1.161E+03
Po215	2.896E-04	3.147E-04	6.053E-04	7.752E-05	1.323E-04	1.471E-04	1.473E-04	1.161E+03
Po216	2.894E-04	3.145E-04	6.051E-04	7.751E-05	1.322E-04	1.470E-04	1.472E-04	1.161E+03
Po218	2.235E-04	2.428E-04	4.672E-04	5.986E-05	1.020E-04	1.135E-04	1.135E-04	1.504E+03
Pr143	9.722E-07	1.469E-06	6.693E-07	6.706E-08	3.896E-07	5.917E-07	4.985E-07	1.225E+06
Pr144	7.660E-03	9.794E-03	1.020E-02	1.234E-03	3.993E-03	5.058E-03	4.461E-03	7.292E+01
Pr144m	1.736E-04	2.245E-04	2.159E-04	2.530E-05	8.714E-05	1.111E-04	9.970E-05	3.557E+03
Pu236	2.150E-04	2.336E-04	4.501E-04	5.769E-05	9.837E-05	1.094E-04	1.094E-04	1.560E+03
Pu238	1.946E-04	2.115E-04	4.079E-04	5.229E-05	8.918E-05	9.920E-05	9.908E-05	1.721E+03
Pu239	1.284E-04	1.395E-04	2.684E-04	3.442E-05	5.859E-05	6.518E-05	6.513E-05	2.615E+03
Pu240	1.029E-03	1.122E-03	2.185E-03	2.802E-04	4.800E-04	5.347E-04	5.316E-04	3.212E+02
Pu241	2.678E-09	2.910E-09	5.597E-09	7.182E-10	1.222E-09	1.359E-09	1.358E-09	1.253E+08
Pu242	8.642E-02	9.430E-02	1.839E-01	2.358E-02	4.043E-02	4.504E-02	4.475E-02	3.817E+00
Pu243	2.638E-07	4.293E-07	1.312E-07	1.256E-08	9.941E-08	1.638E-07	1.339E-07	4.193E+06
Pu244	2.004E+01	2.187E+01	4.271E+01	5.480E+00	9.398E+00	1.047E+01	1.040E+01	1.642E-02
Pu246	2.966E-07	5.288E-07	1.042E-07	9.758E-09	1.073E-07	1.936E-07	1.504E-07	3.404E+06
Ra223	1.930E-04	2.133E-04	3.918E-04	5.008E-05	8.758E-05	9.878E-05	9.798E-05	1.797E+03
Ra224	1.847E-04	2.007E-04	3.860E-04	4.947E-05	8.433E-05	9.379E-05	9.379E-05	1.819E+03
Ra225	4.544E-10	7.648E-10	2.007E-10	1.907E-11	1.685E-10	2.873E-10	2.306E-10	2.354E+09
Ra226	1.010E-04	1.098E-04	2.111E-04	2.709E-05	4.607E-05	5.128E-05	5.121E-05	3.322E+03
Rb86	4.019E-03	5.495E-03	4.147E-03	4.533E-04	1.849E-03	2.462E-03	2.195E-03	1.985E+02
Rb87	3.841E-11	6.711E-11	1.485E-11	1.401E-12	1.404E-11	2.481E-11	1.949E-11	2.682E+10
Re188	1.215E-03	1.611E-03	1.390E-03	1.591E-04	5.855E-04	7.669E-04	6.808E-04	5.658E+02
Rh102	3.642E-03	4.965E-03	3.841E-03	4.281E-04	1.691E-03	2.266E-03	2.002E-03	2.102E+02
Rh106	6.231E-03	8.190E-03	7.520E-03	8.823E-04	3.091E-03	4.001E-03	3.546E-03	1.020E+02
Rn219	3.024E-04	3.351E-04	6.118E-04	7.811E-05	1.372E-04	1.550E-04	1.538E-04	1.152E+03
Rn220	2.617E-04	2.846E-04	5.461E-04	6.994E-05	1.195E-04	1.329E-04	1.330E-04	1.287E+03
Rn222	1.654E-04	1.799E-04	3.450E-04	4.421E-05	7.548E-05	8.404E-05	8.396E-05	2.036E+03
Ru103	2.732E-04	4.199E-04	1.737E-04	1.714E-05	1.081E-04	1.656E-04	1.393E-04	4.286E+03
S35	8.128E-14	1.726E-13	1.340E-14	1.234E-15	2.829E-14	6.020E-14	4.173E-14	1.043E+13
Sb124	2.009E-01	2.596E-01	2.534E-01	2.991E-02	1.017E-01	1.296E-01	1.156E-01	3.009E+00
Sb125	6.470E-04	9.689E-04	4.612E-04	4.627E-05	2.636E-04	3.898E-04	3.330E-04	1.858E+03
Sb126	1.375E-02	1.957E-02	1.198E-02	1.262E-03	5.907E-03	8.390E-03	7.239E-03	7.134E+01
Sb126m	5.038E-03	7.256E-03	4.255E-03	4.457E-04	2.144E-03	3.063E-03	2.656E-03	2.019E+02
Sc46	5.530E-02	7.603E-02	5.564E-02	6.045E-03	2.513E-02	3.385E-02	2.998E-02	1.489E+01
Se75	2.374E-05	3.733E-05	1.365E-05	1.328E-06	9.183E-06	1.449E-05	1.203E-05	4.822E+04
Se79	9.503E-14	2.018E-13	1.567E-14	1.443E-15	3.308E-14	7.038E-14	4.879E-14	8.918E+12
Sm145	6.380E-09	9.971E-09	3.735E-09	3.635E-10	2.476E-09	3.882E-09	3.234E-09	1.805E+08
Sm146	6.242E-07	6.810E-07	1.352E-06	1.728E-07	3.021E-07	3.353E-07	3.313E-07	5.208E+05
Sm147	2.985E-07	3.257E-07	6.465E-07	8.258E-08	1.448E-07	1.606E-07	1.585E-07	1.090E+06
Sm148	4.536E-08	5.013E-08	9.737E-08	1.246E-08	2.227E-08	2.496E-08	2.441E-08	7.223E+06
Sn113	4.138E-08	6.928E-08	2.032E-08	1.981E-09	1.572E-08	2.623E-08	2.111E-08	2.598E+07
Sn123	3.078E-04	4.219E-04	3.150E-04	3.438E-05	1.411E-04	1.885E-04	1.678E-04	2.618E+03
Sn126	6.855E-10	1.151E-09	3.046E-10	2.895E-11	2.544E-10	4.329E-10	3.478E-10	1.563E+09

Table 7.5-2 – Bare Cask Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Sr85	7.113E-04	1.078E-03	4.799E-04	4.759E-05	2.809E-04	4.350E-04	3.639E-04	1.669E+03
Sr89	2.921E-05	4.142E-05	2.596E-05	2.749E-06	1.263E-05	1.783E-05	1.543E-05	3.274E+04
Sr90	3.610E-08	5.817E-08	1.891E-08	1.824E-09	1.373E-08	2.233E-08	1.832E-08	3.094E+07
Ta182	5.997E-02	8.096E-02	6.380E-02	7.059E-03	2.814E-02	3.733E-02	3.292E-02	1.275E+01
Tb160	2.674E-02	3.659E-02	2.698E-02	2.940E-03	1.218E-02	1.650E-02	1.446E-02	3.061E+01
Tc99	1.109E-10	1.896E-10	4.634E-11	4.390E-12	4.086E-11	7.074E-11	5.625E-11	9.492E+09
Tc99m	9.310E-10	1.964E-09	1.622E-10	1.498E-11	3.248E-10	6.863E-10	4.778E-10	9.165E+08
Te121	7.304E-04	1.107E-03	4.924E-04	4.881E-05	2.884E-04	4.467E-04	3.736E-04	1.625E+03
Te121m	1.188E-03	1.625E-03	1.224E-03	1.337E-04	5.459E-04	7.276E-04	6.484E-04	6.729E+02
Te123m	8.572E-10	1.819E-09	1.421E-10	1.309E-11	2.984E-10	6.345E-10	4.401E-10	9.894E+08
Te125m	2.842E-12	6.036E-12	4.685E-13	4.314E-14	9.892E-13	2.105E-12	1.459E-12	2.982E+11
Te127	2.061E-06	3.225E-06	1.203E-06	1.171E-07	7.992E-07	1.255E-06	1.045E-06	5.582E+05
Te127m	2.162E-07	3.225E-07	1.567E-07	1.575E-08	8.845E-08	1.302E-07	1.114E-07	5.582E+06
Te129	4.045E-04	5.585E-04	4.028E-04	4.377E-05	1.835E-04	2.479E-04	2.192E-04	2.056E+03
Te129m	1.421E-04	2.045E-04	1.181E-04	1.227E-05	5.978E-05	8.620E-05	7.432E-05	7.337E+03
Th227	1.640E-04	1.809E-04	3.346E-04	4.278E-05	7.454E-05	8.391E-05	8.333E-05	2.104E+03
Th228	1.548E-04	1.682E-04	3.237E-04	4.150E-05	7.069E-05	7.861E-05	7.858E-05	2.169E+03
Th229	1.075E-04	1.169E-04	2.241E-04	2.876E-05	4.898E-05	5.455E-05	5.446E-05	3.129E+03
Th230	9.363E-05	1.017E-04	1.956E-04	2.511E-05	4.269E-05	4.752E-05	4.745E-05	3.584E+03
Th231	1.824E-09	3.094E-09	7.849E-10	7.446E-11	6.744E-10	1.158E-09	9.254E-10	5.819E+08
Th232	4.428E-05	4.824E-05	9.293E-05	1.198E-05	2.031E-05	2.269E-05	2.255E-05	7.515E+03
Th234	2.592E-12	5.505E-12	4.273E-13	3.934E-14	9.021E-13	1.919E-12	1.331E-12	3.270E+11
Tl206	4.833E-07	6.824E-07	4.242E-07	4.441E-08	2.063E-07	2.947E-07	2.522E-07	2.027E+06
Tl207	3.963E-05	5.625E-05	3.445E-05	3.610E-06	1.691E-05	2.416E-05	2.072E-05	2.493E+04
Tl208	1.409E+00	1.754E+00	2.036E+00	2.551E-01	7.707E-01	9.526E-01	8.510E-01	3.528E-01
Tl209	2.821E-01	3.656E-01	3.491E-01	4.076E-02	1.415E-01	1.802E-01	1.618E-01	2.208E+00
Tm168	1.097E-02	1.540E-02	9.945E-03	1.054E-03	4.759E-03	6.719E-03	5.773E-03	8.535E+01
Tm170	1.071E-06	1.614E-06	7.461E-07	7.493E-08	4.304E-07	6.517E-07	5.495E-07	1.115E+06
Tm171	7.772E-21	1.651E-20	1.281E-21	1.180E-22	2.705E-21	5.756E-21	3.990E-21	1.090E+20
U232	1.443E-04	1.567E-04	3.016E-04	3.867E-05	6.586E-05	7.325E-05	7.321E-05	2.327E+03
U233	1.035E-04	1.124E-04	2.161E-04	2.774E-05	4.718E-05	5.251E-05	5.244E-05	3.244E+03
U234	1.004E-04	1.091E-04	2.097E-04	2.692E-05	4.578E-05	5.095E-05	5.088E-05	3.343E+03
U235	6.624E-05	7.210E-05	1.384E-04	1.778E-05	3.025E-05	3.373E-05	3.362E-05	5.061E+03
U236	8.989E-05	9.777E-05	1.884E-04	2.420E-05	4.118E-05	4.586E-05	4.573E-05	3.719E+03
U237	6.818E-07	1.156E-06	2.932E-07	2.781E-08	2.520E-07	4.327E-07	3.458E-07	1.557E+06
U238	7.916E-03	8.642E-03	1.689E-02	2.167E-03	3.716E-03	4.142E-03	4.110E-03	4.153E+01
U239	9.689E-05	1.368E-04	8.554E-05	8.988E-06	4.146E-05	5.899E-05	5.071E-05	1.001E+04
U240	1.235E-09	2.121E-09	5.073E-10	4.801E-11	4.542E-10	7.895E-10	6.265E-10	8.487E+08
W181	1.158E-12	2.460E-12	1.909E-13	1.758E-14	4.031E-13	8.577E-13	5.945E-13	7.318E+11
W185	3.681E-09	6.085E-09	1.737E-09	1.658E-10	1.377E-09	2.305E-09	1.867E-09	2.958E+08
W188	8.418E-09	1.494E-08	3.016E-09	2.829E-10	3.052E-09	5.481E-09	4.269E-09	1.205E+08
Xe127	5.931E-06	9.801E-06	2.805E-06	2.680E-07	2.221E-06	3.714E-06	3.011E-06	1.837E+05
Xe131m	1.971E-11	4.186E-11	3.249E-12	2.992E-13	6.860E-12	1.460E-11	1.012E-11	4.300E+10
Y88	4.333E-01	5.546E-01	5.541E-01	6.575E-02	2.200E-01	2.795E-01	2.508E-01	1.369E+00

Table 7.5-2 – Bare Cask Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Y89m	1.727E-02	2.398E-02	1.612E-02	1.715E-03	7.496E-03	1.052E-02	9.114E-03	5.248E+01
Y90	3.455E-04	4.686E-04	3.658E-04	4.076E-05	1.605E-04	2.154E-04	1.895E-04	2.208E+03
Y90m	1.812E-04	2.828E-04	1.069E-04	1.042E-05	7.039E-05	1.102E-04	9.190E-05	6.365E+03
Y91	2.404E-04	3.242E-04	2.545E-04	2.821E-05	1.130E-04	1.507E-04	1.317E-04	3.190E+03
Zn65	2.286E-02	3.125E-02	2.362E-02	2.582E-03	1.052E-02	1.401E-02	1.249E-02	3.485E+01
Zr88	2.749E-05	4.501E-05	1.326E-05	1.265E-06	1.031E-05	1.712E-05	1.395E-05	3.999E+04
Zr90m	8.706E-01	1.102E+00	1.201E+00	1.472E-01	4.633E-01	5.811E-01	5.123E-01	6.116E-01
Zr95	4.761E-03	6.863E-03	3.873E-03	3.991E-04	1.988E-03	2.879E-03	2.453E-03	2.255E+02

Notes:

[1] The dose rate at 1-meter from the side of the package bounds the dose rate at 1-meter from the top and bottom of the package based on inspection of the package surface dose rates. Therefore, 1-meter dose rates on the ends of the package are not reported.

Table 7.5-3 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Ac225	4.018E-04	2.212E-04	5.557E-04	1.273E-04	1.656E-05	4.405E-06	1.508E-04	1.751E-04	1.600E-04	3.239E+03	4.086E+03
Ac227	2.758E-06	1.642E-06	4.163E-06	9.580E-07	1.247E-07	3.312E-08	1.036E-06	1.152E-06	1.086E-06	4.324E+05	5.435E+05
Ac228	5.265E-01	1.701E-01	4.287E-01	9.448E-02	1.249E-02	3.573E-03	2.282E-01	2.996E-01	2.487E-01	3.419E+00	5.037E+00
Ag108	3.071E-03	7.968E-04	1.795E-03	3.757E-04	4.719E-05	1.340E-05	1.193E-03	1.720E-03	1.347E-03	5.861E+02	1.343E+03
Ag108m	2.209E-01	5.689E-02	1.273E-01	2.659E-02	3.353E-03	9.466E-04	8.525E-02	1.229E-01	9.645E-02	8.147E+00	1.901E+01
Ag110	2.061E-02	6.336E-03	1.564E-02	3.428E-03	4.518E-04	1.281E-04	8.711E-03	1.171E-02	9.580E-03	8.735E+01	1.405E+02
Ag110m	1.494E+00	4.790E-01	1.202E+00	2.656E-01	3.500E-02	9.899E-03	6.445E-01	8.497E-01	7.037E-01	1.205E+00	1.818E+00
Am241	2.772E-04	1.702E-04	4.330E-04	9.985E-05	1.303E-05	3.454E-06	1.043E-04	1.139E-04	1.089E-04	4.157E+03	5.212E+03
Am242	4.134E-06	8.024E-07	1.547E-06	3.100E-07	3.732E-08	1.029E-08	1.479E-06	2.401E-06	1.739E-06	4.354E+05	1.749E+06
Am242m	2.408E-06	1.476E-06	3.775E-06	8.701E-07	1.136E-07	3.025E-08	9.193E-07	1.005E-06	9.604E-07	4.769E+05	5.951E+05
Am243	2.398E-04	1.471E-04	3.743E-04	8.629E-05	1.125E-05	2.984E-06	9.025E-05	9.860E-05	9.418E-05	4.809E+03	6.032E+03
Am245	5.549E-05	1.063E-05	2.049E-05	4.129E-06	5.011E-07	1.405E-07	1.985E-05	3.247E-05	2.339E-05	3.244E+04	1.281E+05
Am246	1.079E-01	2.814E-02	6.335E-02	1.325E-02	1.661E-03	4.680E-04	4.173E-02	6.000E-02	4.714E-02	1.668E+01	3.846E+01
At217	5.034E-04	3.048E-04	7.749E-04	1.783E-04	2.330E-05	6.179E-06	1.899E-04	2.088E-04	1.985E-04	2.323E+03	2.913E+03
Au198	1.626E-02	3.642E-03	7.558E-03	1.544E-03	1.875E-04	5.288E-05	6.009E-03	9.164E-03	6.930E-03	1.107E+02	3.404E+02
Ba133	3.247E-03	6.113E-04	1.147E-03	2.275E-04	2.740E-05	7.270E-06	1.156E-03	1.886E-03	1.359E-03	5.544E+02	2.476E+03
Ba137m	6.305E-02	1.561E-02	3.410E-02	7.031E-03	8.634E-04	2.477E-04	2.395E-02	3.513E-02	2.719E-02	2.855E+01	7.266E+01
Ba140	1.082E-02	2.514E-03	5.311E-03	1.080E-03	1.338E-04	3.813E-05	4.027E-03	6.053E-03	4.621E-03	1.664E+02	4.721E+02
Be10	3.780E-06	7.205E-07	1.368E-06	2.729E-07	3.276E-08	8.954E-09	1.347E-06	2.194E-06	1.586E-06	4.762E+05	2.010E+06
Bi207	8.691E-01	2.764E-01	6.911E-01	1.508E-01	2.026E-02	5.670E-03	3.729E-01	4.946E-01	4.079E-01	2.071E+00	3.175E+00
Bi210	1.696E-04	4.081E-05	8.838E-05	1.827E-05	2.264E-06	6.390E-07	6.415E-05	9.538E-05	7.326E-05	1.061E+04	2.817E+04
Bi211	9.505E-04	3.843E-04	9.192E-04	2.064E-04	2.664E-05	7.061E-06	3.485E-04	4.703E-04	3.857E-04	1.894E+03	2.549E+03
Bi212	8.049E-02	2.703E-02	6.947E-02	1.548E-02	2.105E-03	6.025E-04	3.574E-02	4.607E-02	3.867E-02	2.236E+01	2.987E+01
Bi213	8.260E-03	2.151E-03	4.876E-03	1.027E-03	1.306E-04	3.652E-05	3.229E-03	4.660E-03	3.647E-03	2.179E+02	4.929E+02
Bi214	1.939E+00	6.855E-01	1.802E+00	4.085E-01	5.584E-02	1.577E-02	8.892E-01	1.123E+00	9.554E-01	9.281E-01	1.141E+00
Bk247	1.065E-04	1.640E-05	2.746E-05	5.410E-06	6.448E-07	1.806E-07	3.662E-05	6.483E-05	4.432E-05	1.691E+04	8.454E+04
Bk249	2.097E-05	1.293E-05	3.322E-05	7.658E-06	1.001E-06	2.673E-07	8.098E-06	8.803E-06	8.455E-06	5.418E+04	6.735E+04
Bk250	5.299E-01	1.611E-01	3.927E-01	8.447E-02	1.099E-02	3.070E-03	2.210E-01	2.991E-01	2.438E-01	3.397E+00	5.863E+00
C14	1.008E-10	9.534E-12	1.226E-11	2.371E-12	2.832E-13	7.287E-14	3.284E-11	7.020E-11	4.256E-11	1.785E+10	8.926E+10
Ca45	5.710E-09	7.966E-10	1.286E-09	2.527E-10	3.015E-11	8.322E-12	1.939E-09	3.604E-09	2.386E-09	3.152E+08	1.576E+09
Cd113	5.910E-08	9.780E-09	1.722E-08	3.402E-09	4.076E-10	1.109E-10	2.057E-08	3.555E-08	2.468E-08	3.046E+07	1.523E+08
Cd113m	4.178E-06	8.029E-07	1.532E-06	3.060E-07	3.676E-08	1.008E-08	1.492E-06	2.422E-06	1.754E-06	4.309E+05	1.785E+06

Table 7.5-3 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Cd115m	2.116E-02	6.515E-03	1.603E-02	3.475E-03	4.527E-04	1.307E-04	8.896E-03	1.198E-02	9.801E-03	8.506E+01	1.378E+02
Ce141	2.441E-06	3.765E-07	6.603E-07	1.310E-07	1.572E-08	4.252E-09	8.417E-07	1.523E-06	1.026E-06	7.375E+05	3.687E+06
Ce144	2.415E-07	2.534E-08	3.536E-08	6.880E-09	8.225E-10	2.153E-10	7.944E-08	1.648E-07	1.018E-07	7.455E+06	3.727E+07
Cf249	3.487E-03	8.884E-04	1.895E-03	4.034E-04	5.058E-05	1.345E-05	1.255E-03	1.936E-03	1.449E-03	5.162E+02	1.339E+03
Cf250	3.094E+01	1.912E+01	4.942E+01	1.142E+01	1.490E+00	3.997E-01	1.209E+01	1.311E+01	1.261E+01	3.642E-02	4.503E-02
Cf251	3.732E-04	2.124E-04	5.353E-04	1.231E-04	1.605E-05	4.257E-06	1.393E-04	1.606E-04	1.475E-04	3.362E+03	4.229E+03
Cf252	1.435E+03	8.837E+02	2.270E+03	5.229E+02	6.837E+01	1.824E+01	5.533E+02	6.014E+02	5.775E+02	7.930E-04	9.867E-04
Cf253	1.178E-06	7.167E-07	1.821E-06	4.196E-07	5.479E-08	1.452E-08	4.431E-07	4.875E-07	4.633E-07	9.884E+05	1.239E+06
Cf254	4.413E+04	2.728E+04	7.050E+04	1.629E+04	2.126E+03	5.702E+02	1.725E+04	1.871E+04	1.799E+04	2.553E-05	3.157E-05
Cl36	2.537E-05	5.540E-06	1.135E-05	2.298E-06	2.816E-07	7.933E-08	9.308E-06	1.437E-05	1.077E-05	7.096E+04	2.269E+05
Cm240	1.589E-03	9.784E-04	2.507E-03	5.774E-04	7.548E-05	2.010E-05	6.088E-04	6.622E-04	6.353E-04	7.181E+02	8.955E+02
Cm242	2.364E-03	1.456E-03	3.736E-03	8.611E-04	1.125E-04	3.001E-05	9.088E-04	9.886E-04	9.488E-04	4.818E+02	5.998E+02
Cm243	4.456E-04	2.260E-04	5.610E-04	1.284E-04	1.671E-05	4.438E-06	1.644E-04	2.037E-04	1.775E-04	3.209E+03	4.056E+03
Cm244	4.551E-02	2.805E-02	7.208E-02	1.661E-02	2.171E-03	5.797E-04	1.757E-02	1.910E-02	1.834E-02	2.497E+01	3.105E+01
Cm245	4.699E-04	2.887E-04	7.379E-04	1.701E-04	2.221E-05	5.907E-06	1.788E-04	1.951E-04	1.867E-04	2.440E+03	3.047E+03
Cm246	1.023E+01	6.303E+00	1.620E+01	3.735E+00	4.880E-01	1.303E-01	3.949E+00	4.293E+00	4.123E+00	1.111E-01	1.381E-01
Cm247	1.095E-02	2.423E-03	4.944E-03	1.008E-03	1.209E-04	3.408E-05	3.987E-03	6.141E-03	4.617E-03	1.644E+02	5.282E+02
Cm248	3.176E+03	1.959E+03	5.037E+03	1.161E+03	1.517E+02	4.054E+01	1.228E+03	1.335E+03	1.282E+03	3.574E-04	4.440E-04
Cm249	1.726E-03	4.205E-04	9.111E-04	1.873E-04	2.305E-05	6.599E-06	6.524E-04	9.633E-04	7.426E-04	1.043E+03	2.728E+03
Cm250	1.889E+01	7.184E+00	1.961E+01	4.593E+00	6.375E-01	1.809E-01	9.081E+00	1.118E+01	9.693E+00	9.180E-02	9.951E-02
Co57	1.456E-04	3.626E-05	7.975E-05	1.653E-05	2.058E-06	5.782E-07	5.526E-05	8.111E-05	6.282E-05	1.236E+04	3.113E+04
Co58	2.929E-01	8.263E-02	1.938E-01	4.121E-02	5.177E-03	1.474E-03	1.176E-01	1.640E-01	1.314E-01	6.146E+00	1.221E+01
Co60	2.041E+00	6.496E-01	1.626E+00	3.546E-01	4.747E-02	1.357E-02	8.738E-01	1.162E+00	9.578E-01	8.820E-01	1.327E+00
Cr51	3.572E-04	6.737E-05	1.265E-04	2.509E-05	3.022E-06	8.016E-07	1.272E-04	2.074E-04	1.496E-04	5.039E+03	2.246E+04
Cs134	3.140E-01	8.700E-02	2.028E-01	4.323E-02	5.523E-03	1.551E-03	1.254E-01	1.758E-01	1.403E-01	5.732E+00	1.161E+01
Cs135	4.496E-10	4.289E-11	5.554E-11	1.074E-11	1.283E-12	3.310E-13	1.466E-10	3.125E-10	1.897E-10	4.003E+09	2.002E+10
Cs137	1.257E-05	2.949E-06	6.316E-06	1.303E-06	1.611E-07	4.534E-08	4.723E-06	7.099E-06	5.412E-06	1.432E+05	3.970E+05
Cu64	2.289E-02	6.228E-03	1.445E-02	3.091E-03	3.947E-04	1.109E-04	9.122E-03	1.291E-02	1.023E-02	7.862E+01	1.624E+02
Dy159	3.691E-08	6.938E-09	1.301E-08	2.580E-09	3.107E-10	8.246E-11	1.313E-08	2.145E-08	1.545E-08	4.877E+07	2.183E+08
Es252	4.073E-02	1.108E-02	2.551E-02	5.385E-03	6.816E-04	1.923E-04	1.607E-02	2.268E-02	1.805E-02	4.419E+01	9.362E+01
Es253	4.475E-03	2.763E-03	7.128E-03	1.646E-03	2.149E-04	5.757E-05	1.742E-03	1.891E-03	1.817E-03	2.525E+02	3.127E+02
Es254	1.831E-03	1.127E-03	2.900E-03	6.692E-04	8.737E-05	2.337E-05	7.085E-04	7.710E-04	7.395E-04	6.207E+02	7.704E+02

Table 7.5-3 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Es254m	2.025E+01	1.251E+01	3.234E+01	7.469E+00	9.749E-01	2.615E-01	7.913E+00	8.586E+00	8.257E+00	5.567E-02	6.882E-02
Eu149	6.446E-04	1.427E-04	2.945E-04	5.962E-05	7.359E-06	2.072E-06	2.374E-04	3.645E-04	2.741E-04	2.792E+03	8.687E+03
Eu150	3.504E-01	1.074E-01	2.641E-01	5.763E-02	7.589E-03	2.135E-03	1.475E-01	1.988E-01	1.625E-01	5.137E+00	8.431E+00
Eu152	7.590E-01	2.432E-01	6.088E-01	1.341E-01	1.757E-02	4.897E-03	3.262E-01	4.316E-01	3.569E-01	2.371E+00	3.676E+00
Eu154	7.919E-01	2.502E-01	6.244E-01	1.363E-01	1.815E-02	5.214E-03	3.381E-01	4.502E-01	3.708E-01	2.273E+00	3.452E+00
Eu155	3.927E-07	3.715E-08	4.781E-08	9.243E-09	1.104E-09	2.841E-10	1.279E-07	2.734E-07	1.657E-07	4.584E+06	2.292E+07
Fe55	2.370E-15	2.241E-16	2.883E-16	5.574E-17	6.657E-18	1.713E-18	7.721E-16	1.650E-15	1.000E-15	7.594E+14	3.797E+15
Fe59	9.927E-01	3.152E-01	7.877E-01	1.716E-01	2.296E-02	6.541E-03	4.244E-01	5.649E-01	4.654E-01	1.813E+00	2.752E+00
Fr221	5.196E-04	2.885E-04	7.254E-04	1.664E-04	2.169E-05	5.759E-06	1.942E-04	2.263E-04	2.062E-04	2.481E+03	3.126E+03
Fr223	2.028E-03	5.438E-04	1.244E-03	2.620E-04	3.301E-05	9.323E-06	7.961E-04	1.132E-03	8.964E-04	8.875E+02	1.931E+03
Gd152	2.278E-07	1.352E-07	3.544E-07	8.184E-08	1.069E-08	2.895E-09	9.399E-08	1.024E-07	9.730E-08	5.079E+06	6.218E+06
Gd153	3.916E-07	3.703E-08	4.763E-08	9.208E-09	1.100E-09	2.830E-10	1.276E-07	2.727E-07	1.653E-07	4.596E+06	2.298E+07
Hf175	3.258E-03	6.199E-04	1.170E-03	2.324E-04	2.797E-05	7.460E-06	1.162E-03	1.888E-03	1.365E-03	5.525E+02	2.413E+03
Hf181	1.278E-02	2.734E-03	5.504E-03	1.112E-03	1.327E-04	3.751E-05	4.652E-03	7.211E-03	5.398E-03	1.408E+02	4.798E+02
Hg203	2.883E-04	4.448E-05	7.450E-05	1.468E-05	1.750E-06	4.901E-07	9.918E-05	1.754E-04	1.200E-04	6.245E+03	3.122E+04
Ho166m	3.505E-01	9.769E-02	2.279E-01	4.843E-02	6.125E-03	1.734E-03	1.399E-01	1.960E-01	1.567E-01	5.135E+00	1.038E+01
I129	5.072E-11	4.796E-12	6.169E-12	1.193E-12	1.425E-13	3.665E-14	1.652E-11	3.531E-11	2.141E-11	3.549E+10	1.775E+11
I131	1.112E-02	2.624E-03	5.627E-03	1.159E-03	1.436E-04	4.037E-05	4.180E-03	6.259E-03	4.780E-03	1.619E+02	4.459E+02
In113m	2.324E-03	4.383E-04	8.233E-04	1.632E-04	1.966E-05	5.215E-06	8.274E-04	1.349E-03	9.731E-04	7.744E+02	3.451E+03
In114	4.578E-03	1.369E-03	3.330E-03	7.203E-04	9.452E-05	2.707E-05	1.901E-03	2.592E-03	2.104E-03	3.932E+02	6.650E+02
In114m	6.465E-03	1.677E-03	3.771E-03	7.889E-04	1.003E-04	2.823E-05	2.502E-03	3.596E-03	2.830E-03	2.784E+02	6.377E+02
In115	1.424E-06	2.627E-07	4.897E-07	9.737E-08	1.168E-08	3.169E-09	5.049E-07	8.332E-07	5.965E-07	1.264E+06	5.680E+06
In115m	1.658E-03	3.128E-04	5.877E-04	1.165E-04	1.403E-05	3.724E-06	5.902E-04	9.622E-04	6.940E-04	1.086E+03	4.833E+03
Ir194	3.060E-02	9.721E-03	2.432E-02	5.346E-03	7.085E-04	1.998E-04	1.314E-02	1.743E-02	1.438E-02	5.883E+01	9.009E+01
K40	1.912E-01	6.397E-02	1.632E-01	3.655E-02	4.779E-03	1.325E-03	8.422E-02	1.093E-01	9.147E-02	9.416E+00	1.359E+01
K42	6.068E-01	2.139E-01	5.618E-01	1.264E-01	1.739E-02	4.992E-03	2.778E-01	3.501E-01	2.978E-01	2.966E+00	3.605E+00
Kr85	1.907E-04	4.426E-05	9.348E-05	1.901E-05	2.357E-06	6.713E-07	7.098E-05	1.068E-04	8.146E-05	9.440E+03	2.681E+04
La140	3.541E+00	1.258E+00	3.320E+00	7.508E-01	1.032E-01	2.958E-02	1.628E+00	2.048E+00	1.746E+00	5.084E-01	6.085E-01
Lu177	4.613E-05	7.404E-06	1.273E-05	2.512E-06	3.001E-07	8.301E-08	1.597E-05	2.785E-05	1.922E-05	3.902E+04	1.951E+05
Lu177m	3.207E-03	6.760E-04	1.352E-03	2.727E-04	3.259E-05	9.155E-06	1.164E-03	1.817E-03	1.353E-03	5.613E+02	1.966E+03
Mn54	2.642E-01	7.397E-02	1.725E-01	3.655E-02	4.553E-03	1.295E-03	1.055E-01	1.477E-01	1.181E-01	6.812E+00	1.390E+01
Na22	1.292E+00	4.110E-01	1.031E+00	2.257E-01	3.023E-02	8.816E-03	5.538E-01	7.363E-01	6.073E-01	1.394E+00	2.042E+00

Table 7.5-3 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Na24	1.204E+01	4.607E+00	1.263E+01	2.966E+00	4.044E-01	1.148E-01	5.788E+00	7.118E+00	6.180E+00	1.425E-01	1.568E-01
Nb91	1.267E-04	2.971E-05	6.305E-05	1.283E-05	1.594E-06	4.547E-07	4.728E-05	7.081E-05	5.418E-05	1.421E+04	3.958E+04
Nb94	4.228E-01	1.161E-01	2.684E-01	5.673E-02	7.131E-03	2.019E-03	1.674E-01	2.358E-01	1.879E-01	4.257E+00	8.917E+00
Nb95	1.588E-01	4.220E-02	9.605E-02	2.021E-02	2.582E-03	7.245E-04	6.200E-02	8.819E-02	6.989E-02	1.134E+01	2.484E+01
Nb95m	1.374E-04	2.525E-05	4.789E-05	9.681E-06	1.188E-06	3.342E-07	4.888E-05	8.150E-05	5.797E-05	1.310E+04	5.387E+04
Nd144	5.907E-08	3.057E-08	8.108E-08	1.877E-08	2.490E-09	6.823E-10	2.564E-08	2.946E-08	2.692E-08	2.220E+07	2.638E+07
Ni59	2.986E-08	7.001E-09	1.486E-08	3.025E-09	3.756E-10	1.072E-10	1.114E-08	1.669E-08	1.277E-08	6.029E+07	1.680E+08
Np235	1.306E-08	3.933E-09	9.070E-09	2.056E-09	2.658E-10	7.036E-11	4.514E-09	7.608E-09	5.357E-09	1.379E+08	2.558E+08
Np237	1.633E-04	9.984E-05	2.538E-04	5.849E-05	7.615E-06	2.022E-06	6.137E-05	6.723E-05	6.411E-05	7.093E+03	8.902E+03
Np238	3.471E-01	1.055E-01	2.571E-01	5.529E-02	7.191E-03	2.009E-03	1.447E-01	1.960E-01	1.597E-01	5.185E+00	8.961E+00
Np239	2.479E-04	4.307E-05	7.759E-05	1.536E-05	1.842E-06	4.995E-07	8.697E-05	1.470E-04	1.036E-04	7.261E+03	3.603E+04
Np240	2.960E-01	8.480E-02	2.004E-01	4.263E-02	5.352E-03	1.519E-03	1.197E-01	1.659E-01	1.333E-01	6.082E+00	1.185E+01
Np240m	1.152E-01	3.679E-02	9.233E-02	2.040E-02	2.699E-03	7.647E-04	4.970E-02	6.564E-02	5.428E-02	1.562E+01	2.354E+01
Os185	9.201E-02	2.388E-02	5.356E-02	1.117E-02	1.384E-03	3.951E-04	3.561E-02	5.131E-02	4.021E-02	1.956E+01	4.556E+01
Os194	2.141E-17	2.025E-18	2.605E-18	5.035E-19	6.015E-20	1.548E-20	6.975E-18	1.491E-17	9.038E-18	8.406E+16	4.203E+17
P32	1.578E-03	4.314E-04	1.001E-03	2.122E-04	2.707E-05	7.634E-06	6.276E-04	8.871E-04	7.037E-04	1.141E+03	2.358E+03
P33	4.211E-09	5.681E-10	9.019E-10	1.771E-10	2.112E-11	5.822E-12	1.424E-09	2.684E-09	1.761E-09	4.274E+08	2.137E+09
Pa231	4.807E-04	1.713E-04	3.994E-04	8.873E-05	1.136E-05	3.018E-06	1.751E-04	2.469E-04	1.964E-04	3.744E+03	5.964E+03
Pa233	2.131E-03	4.087E-04	7.754E-04	1.542E-04	1.854E-05	4.968E-06	7.609E-04	1.233E-03	8.933E-04	8.446E+02	3.623E+03
Pa234	6.224E-01	1.938E-01	4.794E-01	1.049E-01	1.365E-02	3.883E-03	2.639E-01	3.525E-01	2.897E-01	2.892E+00	4.636E+00
Pa234m	1.710E-02	5.400E-03	1.347E-02	2.951E-03	3.916E-04	1.106E-04	7.312E-03	9.723E-03	8.010E-03	1.053E+02	1.628E+02
Pb209	6.432E-06	1.276E-06	2.480E-06	4.971E-07	5.986E-08	1.653E-08	2.311E-06	3.704E-06	2.706E-06	2.799E+05	1.089E+06
Pb210	7.521E-13	4.639E-13	1.188E-12	2.739E-13	3.570E-14	9.541E-15	2.874E-13	3.152E-13	3.031E-13	1.515E+12	1.887E+12
Pb211	1.380E-02	3.819E-03	8.874E-03	1.880E-03	2.365E-04	6.693E-05	5.493E-03	7.723E-03	6.157E-03	1.305E+02	2.689E+02
Pb212	2.754E-04	4.670E-05	8.294E-05	1.640E-05	1.965E-06	5.355E-07	9.622E-05	1.642E-04	1.149E-04	6.536E+03	3.268E+04
Pb214	5.031E-03	1.233E-03	2.706E-03	5.636E-04	7.041E-05	1.971E-05	1.921E-03	2.840E-03	2.189E-03	3.578E+02	9.132E+02
Pm145	6.965E-17	2.606E-17	7.058E-17	1.642E-17	2.267E-18	6.420E-19	3.311E-17	4.102E-17	3.542E-17	2.550E+16	2.804E+16
Pm146	1.012E-01	2.637E-02	5.943E-02	1.247E-02	1.585E-03	4.451E-04	3.924E-02	5.629E-02	4.435E-02	1.779E+01	4.044E+01
Pm147	1.059E-09	1.179E-10	1.696E-10	3.308E-11	3.947E-12	1.057E-12	3.503E-10	7.109E-10	4.451E-10	1.700E+09	8.502E+09
Pm148	4.680E-01	1.535E-01	3.883E-01	8.651E-02	1.126E-02	3.132E-03	2.039E-01	2.668E-01	2.222E-01	3.846E+00	5.747E+00
Pm148m	4.067E-01	1.147E-01	2.697E-01	5.729E-02	7.374E-03	2.068E-03	1.637E-01	2.285E-01	1.827E-01	4.426E+00	8.703E+00
Po209	1.244E-03	3.481E-04	8.114E-04	1.720E-04	2.142E-05	6.093E-06	4.965E-04	6.954E-04	5.559E-04	1.447E+03	2.954E+03

Table 7.5-3 – [redacted]SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Po210	2.483E-04	1.518E-04	3.861E-04	8.901E-05	1.160E-05	3.079E-06	9.351E-05	1.023E-04	9.763E-05	4.661E+03	5.847E+03
Po211	2.169E-03	7.618E-04	1.830E-03	4.012E-04	5.105E-05	1.408E-05	8.496E-04	1.140E-03	9.391E-04	8.299E+02	1.279E+03
Po212	4.906E-04	3.016E-04	7.678E-04	1.768E-04	2.311E-05	6.126E-06	1.850E-04	2.017E-04	1.930E-04	2.345E+03	2.938E+03
Po213	4.982E-04	3.036E-04	7.724E-04	1.778E-04	2.324E-05	6.161E-06	1.880E-04	2.059E-04	1.963E-04	2.330E+03	2.922E+03
Po214	5.071E-04	3.060E-04	7.777E-04	1.789E-04	2.338E-05	6.201E-06	1.914E-04	2.108E-04	2.002E-04	2.314E+03	2.903E+03
Po215	5.073E-04	3.056E-04	7.764E-04	1.786E-04	2.333E-05	6.188E-06	1.913E-04	2.110E-04	2.002E-04	2.318E+03	2.909E+03
Po216	4.956E-04	3.030E-04	7.710E-04	1.775E-04	2.320E-05	6.150E-06	1.870E-04	2.045E-04	1.952E-04	2.335E+03	2.927E+03
Po218	3.813E-04	2.335E-04	5.940E-04	1.369E-04	1.787E-05	4.739E-06	1.436E-04	1.570E-04	1.499E-04	3.030E+03	3.799E+03
Pr143	5.767E-05	1.294E-05	2.696E-05	5.503E-06	6.750E-07	1.898E-07	2.134E-05	3.260E-05	2.460E-05	3.121E+04	9.484E+04
Pr144	7.418E-02	2.671E-02	7.076E-02	1.622E-02	2.225E-03	6.176E-04	3.446E-02	4.321E-02	3.698E-02	2.426E+01	2.914E+01
Pr144m	1.944E-03	6.796E-04	1.779E-03	4.013E-04	5.448E-05	1.575E-05	8.850E-04	1.120E-03	9.509E-04	9.261E+02	1.143E+03
Pu236	3.642E-04	2.239E-04	5.701E-04	1.314E-04	1.716E-05	4.552E-06	1.374E-04	1.499E-04	1.433E-04	3.157E+03	3.955E+03
Pu238	3.290E-04	2.024E-04	5.158E-04	1.189E-04	1.552E-05	4.120E-06	1.243E-04	1.356E-04	1.297E-04	3.489E+03	4.369E+03
Pu239	2.177E-04	1.337E-04	3.401E-04	7.841E-05	1.022E-05	2.711E-06	8.189E-05	8.941E-05	8.545E-05	5.293E+03	6.639E+03
Pu240	1.730E-03	1.066E-03	2.739E-03	6.316E-04	8.250E-05	2.203E-05	6.668E-04	7.252E-04	6.962E-04	6.571E+02	8.172E+02
Pu241	4.541E-09	2.787E-09	7.090E-09	1.635E-09	2.129E-10	5.651E-11	1.708E-09	1.866E-09	1.783E-09	2.539E+08	3.185E+08
Pu242	1.452E-01	8.953E-02	2.303E-01	5.309E-02	6.937E-03	1.853E-03	5.614E-02	6.104E-02	5.863E-02	7.818E+00	9.712E+00
Pu243	3.195E-05	6.087E-06	1.151E-05	2.287E-06	2.751E-07	7.357E-08	1.139E-05	1.851E-05	1.339E-05	5.634E+04	2.447E+05
Pu244	3.360E+01	2.073E+01	5.337E+01	1.231E+01	1.608E+00	4.301E-01	1.302E+01	1.415E+01	1.360E+01	3.373E-02	4.185E-02
Pu246	8.562E-05	1.315E-05	2.200E-05	4.334E-06	5.166E-07	1.446E-07	2.944E-05	5.220E-05	3.565E-05	2.102E+04	1.051E+05
Ra223	9.853E-04	3.300E-04	7.614E-04	1.676E-04	2.135E-05	5.738E-06	3.609E-04	5.138E-04	4.065E-04	1.827E+03	3.137E+03
Ra224	3.316E-04	1.956E-04	4.951E-04	1.140E-04	1.486E-05	3.943E-06	1.243E-04	1.397E-04	1.307E-04	3.635E+03	4.565E+03
Ra225	8.277E-08	1.395E-08	2.479E-08	4.901E-09	5.877E-10	1.593E-10	2.890E-08	4.954E-08	3.457E-08	2.175E+07	1.087E+08
Ra226	1.713E-04	1.052E-04	2.675E-04	6.166E-05	8.028E-06	2.132E-06	6.445E-05	7.037E-05	6.727E-05	6.729E+03	8.444E+03
Rb86	7.304E-02	2.265E-02	5.582E-02	1.206E-02	1.604E-03	4.434E-04	3.080E-02	4.140E-02	3.388E-02	2.464E+01	4.060E+01
Rb87	1.064E-08	1.586E-09	2.648E-09	5.216E-10	6.232E-11	1.715E-11	3.646E-09	6.591E-09	4.443E-09	1.692E+08	8.459E+08
Re188	1.875E-02	5.944E-03	1.487E-02	3.275E-03	4.323E-04	1.239E-04	8.052E-03	1.067E-02	8.808E-03	9.599E+01	1.453E+02
Rh102	7.464E-02	2.176E-02	5.229E-02	1.127E-02	1.480E-03	4.131E-04	3.070E-02	4.227E-02	3.406E-02	2.412E+01	4.357E+01
Rh106	8.936E-02	2.852E-02	7.175E-02	1.591E-02	2.127E-03	6.000E-04	3.861E-02	5.110E-02	4.222E-02	2.014E+01	3.000E+01
Rn219	1.554E-03	5.288E-04	1.226E-03	2.694E-04	3.417E-05	9.260E-06	5.723E-04	8.027E-04	6.426E-04	1.158E+03	1.944E+03
Rn220	4.882E-04	2.827E-04	7.148E-04	1.641E-04	2.141E-05	5.686E-06	1.838E-04	2.074E-04	1.935E-04	2.518E+03	3.166E+03
Rn222	3.096E-04	1.788E-04	4.518E-04	1.038E-04	1.352E-05	3.592E-06	1.164E-04	1.317E-04	1.226E-04	3.984E+03	5.011E+03

Table 7.5-3 – [redacted]SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Ru103	1.802E-02	4.009E-03	8.260E-03	1.679E-03	2.019E-04	5.741E-05	6.627E-03	1.013E-02	7.648E-03	9.991E+01	3.135E+02
S35	1.483E-10	1.402E-11	1.804E-11	3.487E-12	4.165E-13	1.072E-13	4.830E-11	1.032E-10	6.259E-11	1.214E+10	6.069E+10
Sb124	2.182E+00	7.688E-01	2.019E+00	4.561E-01	6.263E-02	1.780E-02	9.994E-01	1.261E+00	1.073E+00	8.248E-01	1.011E+00
Sb125	3.140E-02	7.576E-03	1.633E-02	3.358E-03	4.107E-04	1.175E-04	1.183E-02	1.753E-02	1.349E-02	5.733E+01	1.532E+02
Sb126	4.261E-01	1.138E-01	2.601E-01	5.476E-02	6.912E-03	1.959E-03	1.670E-01	2.380E-01	1.879E-01	4.224E+00	9.188E+00
Sb126m	1.769E-01	4.564E-02	1.024E-01	2.139E-02	2.679E-03	7.559E-04	6.837E-02	9.881E-02	7.723E-02	1.017E+01	2.381E+01
Sc46	1.088E+00	3.300E-01	8.042E-01	1.730E-01	2.273E-02	6.316E-03	4.532E-01	6.145E-01	5.003E-01	1.655E+00	2.850E+00
Se75	2.067E-03	4.248E-04	8.397E-04	1.693E-04	2.019E-05	5.707E-06	7.465E-04	1.179E-03	8.714E-04	8.706E+02	3.154E+03
Se79	1.734E-10	1.639E-11	2.109E-11	4.077E-12	4.870E-13	1.253E-13	5.647E-11	1.207E-10	7.318E-11	1.038E+10	5.191E+10
Sm145	4.947E-07	1.062E-07	2.139E-07	4.325E-08	5.154E-09	1.460E-09	1.801E-07	2.788E-07	2.090E-07	3.638E+06	1.233E+07
Sm146	1.056E-06	6.478E-07	1.687E-06	3.898E-07	5.095E-08	1.374E-08	4.253E-07	4.596E-07	4.420E-07	1.067E+06	1.310E+06
Sm147	5.116E-07	3.109E-07	8.106E-07	1.872E-07	2.443E-08	6.595E-09	2.076E-07	2.241E-07	2.147E-07	2.221E+06	2.729E+06
Sm148	9.382E-08	5.228E-08	1.379E-07	3.190E-08	4.197E-09	1.144E-09	3.969E-08	4.448E-08	4.142E-08	1.306E+07	1.574E+07
Sn113	8.143E-06	1.320E-06	2.298E-06	4.561E-07	5.464E-08	1.537E-08	2.826E-06	4.921E-06	3.400E-06	2.211E+05	1.105E+06
Sn123	5.830E-03	1.782E-03	4.363E-03	9.403E-04	1.247E-04	3.451E-05	2.442E-03	3.302E-03	2.692E-03	3.087E+02	5.217E+02
Sn126	1.219E-07	2.071E-08	3.693E-08	7.301E-09	8.758E-10	2.372E-10	4.261E-08	7.281E-08	5.092E-08	1.477E+07	7.383E+07
Sr85	3.865E-02	9.064E-03	1.924E-02	3.917E-03	4.864E-04	1.388E-04	1.442E-02	2.160E-02	1.653E-02	4.657E+01	1.297E+02
Sr89	9.004E-04	2.383E-04	5.435E-04	1.144E-04	1.447E-05	4.081E-06	3.531E-04	5.056E-04	3.978E-04	1.999E+03	4.410E+03
Sr90	4.136E-06	7.896E-07	1.500E-06	2.993E-07	3.591E-08	9.817E-09	1.475E-06	2.401E-06	1.735E-06	4.352E+05	1.834E+06
Ta182	9.926E-01	3.152E-01	7.878E-01	1.717E-01	2.296E-02	6.538E-03	4.244E-01	5.648E-01	4.654E-01	1.813E+00	2.753E+00
Tb160	5.230E-01	1.588E-01	3.872E-01	8.349E-02	1.085E-02	3.082E-03	2.180E-01	2.954E-01	2.407E-01	3.441E+00	5.841E+00
Tc99	2.444E-08	3.888E-09	6.712E-09	1.325E-09	1.586E-10	4.334E-11	8.457E-09	1.487E-08	1.021E-08	7.364E+07	3.682E+08
Tc99m	1.652E-06	1.565E-07	2.017E-07	3.901E-08	4.660E-09	1.199E-09	5.382E-07	1.150E-06	6.972E-07	1.090E+06	5.448E+06
Te121	3.979E-02	9.325E-03	1.979E-02	4.028E-03	5.001E-04	1.427E-04	1.485E-02	2.224E-02	1.701E-02	4.524E+01	1.262E+02
Te121m	2.184E-02	6.736E-03	1.657E-02	3.576E-03	4.751E-04	1.314E-04	9.192E-03	1.239E-02	1.012E-02	8.240E+01	1.370E+02
Te123m	1.557E-06	1.473E-07	1.896E-07	3.666E-08	4.378E-09	1.127E-09	5.073E-07	1.084E-06	6.573E-07	1.156E+06	5.779E+06
Te125m	5.185E-09	4.903E-10	6.307E-10	1.219E-10	1.456E-11	3.747E-12	1.689E-09	3.610E-09	2.188E-09	3.472E+08	1.736E+09
Te127	1.632E-04	3.475E-05	6.979E-05	1.410E-05	1.682E-06	4.751E-07	5.933E-05	9.216E-05	6.889E-05	1.103E+04	3.788E+04
Te127m	9.831E-06	2.421E-06	5.276E-06	1.087E-06	1.336E-07	3.830E-08	3.728E-06	5.480E-06	4.236E-06	1.831E+05	4.699E+05
Te129	8.912E-03	2.580E-03	6.167E-03	1.320E-03	1.726E-04	4.808E-05	3.643E-03	5.039E-03	4.050E-03	2.020E+02	3.744E+02
Te129m	4.808E-03	1.261E-03	2.850E-03	5.973E-04	7.540E-05	2.116E-05	1.865E-03	2.677E-03	2.105E-03	3.743E+02	8.505E+02
Th227	8.482E-04	2.750E-04	6.296E-04	1.389E-04	1.774E-05	4.738E-06	3.084E-04	4.497E-04	3.496E-04	2.122E+03	3.799E+03

Table 7.5-3 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Th228	2.630E-04	1.613E-04	4.102E-04	9.459E-05	1.234E-05	3.272E-06	9.894E-05	1.082E-04	1.033E-04	4.388E+03	5.502E+03
Th229	2.096E-04	1.166E-04	2.931E-04	6.728E-05	8.744E-06	2.324E-06	7.816E-05	9.109E-05	8.299E-05	6.141E+03	7.744E+03
Th230	1.583E-04	9.734E-05	2.476E-04	5.707E-05	7.429E-06	1.973E-06	5.955E-05	6.495E-05	6.214E-05	7.270E+03	9.123E+03
Th231	3.648E-07	5.975E-08	1.047E-07	2.067E-08	2.477E-09	6.743E-10	1.268E-07	2.202E-07	1.524E-07	4.934E+06	2.467E+07
Th232	7.422E-05	4.571E-05	1.166E-04	2.687E-05	3.496E-06	9.319E-07	2.813E-05	3.073E-05	2.949E-05	1.543E+04	1.931E+04
Th234	4.728E-09	4.471E-10	5.751E-10	1.112E-10	1.328E-11	3.417E-12	1.540E-09	3.292E-09	1.996E-09	3.807E+08	1.903E+09
Tl206	1.322E-05	3.700E-06	8.627E-06	1.828E-06	2.277E-07	6.479E-08	5.278E-06	7.390E-06	5.909E-06	1.362E+05	2.778E+05
Tl207	1.185E-03	3.204E-04	7.362E-04	1.553E-04	1.941E-05	5.504E-06	4.672E-04	6.634E-04	5.254E-04	1.519E+03	3.270E+03
Tl208	1.031E+01	4.022E+00	1.113E+01	2.628E+00	3.602E-01	1.026E-01	5.022E+00	6.130E+00	5.350E+00	1.617E-01	1.755E-01
Tl209	3.126E+00	1.103E+00	2.898E+00	6.519E-01	8.982E-02	2.580E-02	1.432E+00	1.804E+00	1.535E+00	5.758E-01	6.976E-01
Tm168	2.885E-01	8.100E-02	1.896E-01	4.030E-02	5.082E-03	1.446E-03	1.156E-01	1.615E-01	1.292E-01	6.239E+00	1.245E+01
Tm170	6.174E-05	1.395E-05	2.918E-05	5.963E-06	7.322E-07	2.060E-07	2.289E-05	3.488E-05	2.636E-05	2.915E+04	8.738E+04
Tm171	1.418E-17	1.341E-18	1.725E-18	3.334E-19	3.983E-20	1.025E-20	4.619E-18	9.873E-18	5.985E-18	1.269E+17	6.347E+17
U232	2.442E-04	1.502E-04	3.821E-04	8.810E-05	1.149E-05	3.047E-06	9.189E-05	1.003E-04	9.587E-05	4.711E+03	5.908E+03
U233	1.755E-04	1.077E-04	2.740E-04	6.315E-05	8.223E-06	2.183E-06	6.602E-05	7.212E-05	6.891E-05	6.570E+03	8.246E+03
U234	1.698E-04	1.044E-04	2.656E-04	6.123E-05	7.972E-06	2.117E-06	6.387E-05	6.965E-05	6.663E-05	6.777E+03	8.504E+03
U235	1.401E-04	7.306E-05	1.822E-04	4.174E-05	5.414E-06	1.442E-06	5.194E-05	6.328E-05	5.585E-05	9.877E+03	1.248E+04
U236	1.515E-04	9.326E-05	2.377E-04	5.479E-05	7.132E-06	1.897E-06	5.733E-05	6.247E-05	5.984E-05	7.572E+03	9.487E+03
U237	1.306E-04	2.190E-05	3.866E-05	7.641E-06	9.153E-07	2.498E-07	4.554E-05	7.807E-05	5.449E-05	1.379E+04	6.893E+04
U238	1.326E-02	8.185E-03	2.108E-02	4.865E-03	6.352E-04	1.700E-04	5.145E-03	5.593E-03	5.374E-03	8.538E+01	1.059E+02
U239	2.708E-03	7.494E-04	1.740E-03	3.680E-04	4.588E-05	1.305E-05	1.078E-03	1.515E-03	1.207E-03	6.646E+02	1.380E+03
U240	2.744E-07	4.401E-08	7.599E-08	1.500E-08	1.794E-09	4.925E-10	9.502E-08	1.662E-07	1.145E-07	6.560E+06	3.280E+07
W181	2.113E-09	1.998E-10	2.570E-10	4.968E-11	5.934E-12	1.527E-12	6.882E-10	1.471E-09	8.918E-10	8.519E+08	4.260E+09
W185	5.495E-07	9.801E-08	1.793E-07	3.555E-08	4.268E-09	1.152E-09	1.937E-07	3.241E-07	2.298E-07	3.275E+06	1.562E+07
W188	2.341E-06	3.629E-07	6.098E-07	1.202E-07	1.433E-08	4.006E-09	8.060E-07	1.424E-06	9.747E-07	7.689E+05	3.845E+06
Xe127	8.724E-04	1.568E-04	2.876E-04	5.699E-05	6.852E-06	1.842E-06	3.079E-04	5.131E-04	3.648E-04	2.063E+03	9.771E+03
Xe131m	3.596E-08	3.400E-09	4.373E-09	8.455E-10	1.010E-10	2.599E-11	1.171E-08	2.503E-08	1.518E-08	5.006E+07	2.503E+08
Y88	4.432E+00	1.586E+00	4.190E+00	9.590E-01	1.271E-01	3.725E-02	2.043E+00	2.563E+00	2.192E+00	4.061E-01	4.833E-01
Y89m	4.037E-01	1.177E-01	2.802E-01	5.973E-02	7.398E-03	2.115E-03	1.645E-01	2.261E-01	1.826E-01	4.459E+00	8.511E+00
Y90	6.644E-03	1.986E-03	4.827E-03	1.046E-03	1.367E-04	3.867E-05	2.762E-03	3.760E-03	3.053E-03	2.709E+02	4.655E+02
Y90m	1.406E-02	3.006E-03	6.053E-03	1.224E-03	1.460E-04	4.135E-05	5.115E-03	7.935E-03	5.938E-03	1.280E+02	4.353E+02
Y91	4.221E-03	1.306E-03	3.232E-03	7.037E-04	9.349E-05	2.711E-05	1.784E-03	2.400E-03	1.964E-03	4.265E+02	6.639E+02

Table 7.5-3 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Zn65	4.132E-01	1.284E-01	3.167E-01	6.841E-02	9.110E-03	2.517E-03	1.744E-01	2.343E-01	1.918E-01	4.356E+00	7.151E+00
Zr88	3.507E-03	6.613E-04	1.242E-03	2.463E-04	2.967E-05	7.869E-06	1.249E-03	2.036E-03	1.468E-03	5.133E+02	2.287E+03
Zr90m	7.151E+00	2.722E+00	7.375E+00	1.714E+00	2.383E-01	6.578E-02	3.445E+00	4.211E+00	3.664E+00	2.441E-01	2.736E-01
Zr95	1.569E-01	4.171E-02	9.494E-02	1.997E-02	2.552E-03	7.161E-04	6.128E-02	8.717E-02	6.908E-02	1.147E+01	2.514E+01

Table 7.5-4 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Ac225	4.018E-04	2.212E-04	5.557E-04	6.945E-05	1.508E-04	1.751E-04	1.600E-04	1.296E+03
Ac227	2.758E-06	1.642E-06	4.163E-06	5.237E-07	1.036E-06	1.152E-06	1.086E-06	1.719E+05
Ac228	5.265E-01	1.701E-01	4.287E-01	5.107E-02	2.282E-01	2.996E-01	2.487E-01	1.762E+00
Ag108	3.071E-03	7.968E-04	1.795E-03	1.995E-04	1.193E-03	1.720E-03	1.347E-03	4.512E+02
Ag108m	2.209E-01	5.689E-02	1.273E-01	1.403E-02	8.525E-02	1.229E-01	9.645E-02	6.416E+00
Ag110	2.061E-02	6.336E-03	1.564E-02	1.847E-03	8.711E-03	1.171E-02	9.580E-03	4.874E+01
Ag110m	1.494E+00	4.790E-01	1.202E+00	1.431E-01	6.445E-01	8.497E-01	7.037E-01	6.290E-01
Am241	2.772E-04	1.702E-04	4.330E-04	5.457E-05	1.043E-04	1.139E-04	1.089E-04	1.649E+03
Am242	4.134E-06	8.024E-07	1.547E-06	1.629E-07	1.479E-06	2.401E-06	1.739E-06	4.354E+05
Am242m	2.408E-06	1.476E-06	3.775E-06	4.761E-07	9.193E-07	1.005E-06	9.604E-07	1.890E+05
Am243	2.398E-04	1.471E-04	3.743E-04	4.717E-05	9.025E-05	9.860E-05	9.418E-05	1.908E+03
Am245	5.549E-05	1.063E-05	2.049E-05	2.167E-06	1.985E-05	3.247E-05	2.339E-05	3.244E+04
Am246	1.079E-01	2.814E-02	6.335E-02	7.029E-03	4.173E-02	6.000E-02	4.714E-02	1.280E+01
At217	5.034E-04	3.048E-04	7.749E-04	9.748E-05	1.899E-04	2.088E-04	1.985E-04	9.233E+02
Au198	1.626E-02	3.642E-03	7.558E-03	8.116E-04	6.009E-03	9.164E-03	6.930E-03	1.107E+02
Ba133	3.247E-03	6.113E-04	1.147E-03	1.200E-04	1.156E-03	1.886E-03	1.359E-03	5.544E+02
Ba137m	6.305E-02	1.561E-02	3.410E-02	3.698E-03	2.395E-02	3.513E-02	2.719E-02	2.434E+01
Ba140	1.082E-02	2.514E-03	5.311E-03	5.753E-04	4.027E-03	6.053E-03	4.621E-03	1.564E+02
Be10	3.780E-06	7.205E-07	1.368E-06	1.433E-07	1.347E-06	2.194E-06	1.586E-06	4.762E+05
Bi207	8.691E-01	2.764E-01	6.911E-01	8.174E-02	3.729E-01	4.946E-01	4.079E-01	1.101E+00
Bi210	1.696E-04	4.081E-05	8.838E-05	9.672E-06	6.415E-05	9.538E-05	7.326E-05	9.305E+03
Bi211	9.505E-04	3.843E-04	9.192E-04	1.122E-04	3.485E-04	4.703E-04	3.857E-04	8.020E+02
Bi212	8.049E-02	2.703E-02	6.947E-02	8.405E-03	3.574E-02	4.607E-02	3.867E-02	1.071E+01
Bi213	8.260E-03	2.151E-03	4.876E-03	5.479E-04	3.229E-03	4.660E-03	3.647E-03	1.643E+02
Bi214	1.939E+00	6.855E-01	1.802E+00	2.224E-01	8.892E-01	1.123E+00	9.554E-01	4.046E-01
Bk247	1.065E-04	1.640E-05	2.746E-05	2.805E-06	3.662E-05	6.483E-05	4.432E-05	1.691E+04
Bk249	2.097E-05	1.293E-05	3.322E-05	4.194E-06	8.098E-06	8.803E-06	8.455E-06	2.146E+04
Bk250	5.299E-01	1.611E-01	3.927E-01	4.552E-02	2.210E-01	2.991E-01	2.438E-01	1.977E+00
C14	1.008E-10	9.534E-12	1.226E-11	1.225E-12	3.284E-11	7.020E-11	4.256E-11	1.785E+10
Ca45	5.710E-09	7.966E-10	1.286E-09	1.311E-10	1.939E-09	3.604E-09	2.386E-09	3.152E+08
Cd113	5.910E-08	9.780E-09	1.722E-08	1.779E-09	2.057E-08	3.555E-08	2.468E-08	3.046E+07
Cd113m	4.178E-06	8.029E-07	1.532E-06	1.607E-07	1.492E-06	2.422E-06	1.754E-06	4.309E+05
Cd115m	2.116E-02	6.515E-03	1.603E-02	1.865E-03	8.896E-03	1.198E-02	9.801E-03	4.824E+01
Ce141	2.441E-06	3.765E-07	6.603E-07	6.861E-08	8.417E-07	1.523E-06	1.026E-06	7.375E+05
Ce144	2.415E-07	2.534E-08	3.536E-08	3.566E-09	7.944E-08	1.648E-07	1.018E-07	7.455E+06
Cf249	3.487E-03	8.884E-04	1.895E-03	2.166E-04	1.255E-03	1.936E-03	1.449E-03	4.155E+02
Cf250	3.094E+01	1.912E+01	4.942E+01	6.252E+00	1.209E+01	1.311E+01	1.261E+01	1.440E-02
Cf251	3.732E-04	2.124E-04	5.353E-04	6.723E-05	1.393E-04	1.606E-04	1.475E-04	1.339E+03
Cf252	1.435E+03	8.837E+02	2.270E+03	2.864E+02	5.533E+02	6.014E+02	5.775E+02	3.143E-04
Cf253	1.178E-06	7.167E-07	1.821E-06	2.294E-07	4.431E-07	4.875E-07	4.633E-07	3.924E+05
Cf254	4.413E+04	2.728E+04	7.050E+04	8.919E+03	1.725E+04	1.871E+04	1.799E+04	1.009E-05
Cl36	2.537E-05	5.540E-06	1.135E-05	1.217E-06	9.308E-06	1.437E-05	1.077E-05	7.096E+04
Cm240	1.589E-03	9.784E-04	2.507E-03	3.161E-04	6.088E-04	6.622E-04	6.353E-04	2.848E+02
Cm242	2.364E-03	1.456E-03	3.736E-03	4.715E-04	9.088E-04	9.886E-04	9.488E-04	1.909E+02

Table 7.5-4 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side(1)	Top	Bottom	Side	
Cm243	4.456E-04	2.260E-04	5.610E-04	7.004E-05	1.644E-04	2.037E-04	1.775E-04	1.285E+03
Cm244	4.551E-02	2.805E-02	7.208E-02	9.099E-03	1.757E-02	1.910E-02	1.834E-02	9.892E+00
Cm245	4.699E-04	2.887E-04	7.379E-04	9.306E-05	1.788E-04	1.951E-04	1.867E-04	9.671E+02
Cm246	1.023E+01	6.303E+00	1.620E+01	2.045E+00	3.949E+00	4.293E+00	4.123E+00	4.400E-02
Cm247	1.095E-02	2.423E-03	4.944E-03	5.285E-04	3.987E-03	6.141E-03	4.617E-03	1.644E+02
Cm248	3.176E+03	1.959E+03	5.037E+03	6.361E+02	1.228E+03	1.335E+03	1.282E+03	1.415E-04
Cm249	1.726E-03	4.205E-04	9.111E-04	9.878E-05	6.524E-04	9.633E-04	7.426E-04	9.112E+02
Cm250	1.889E+01	7.184E+00	1.961E+01	2.532E+00	9.081E+00	1.118E+01	9.693E+00	3.554E-02
Co57	1.456E-04	3.626E-05	7.975E-05	8.759E-06	5.526E-05	8.111E-05	6.282E-05	1.028E+04
Co58	2.929E-01	8.263E-02	1.938E-01	2.206E-02	1.176E-01	1.640E-01	1.314E-01	4.080E+00
Co60	2.041E+00	6.496E-01	1.626E+00	1.912E-01	8.738E-01	1.162E+00	9.578E-01	4.708E-01
Cr51	3.572E-04	6.737E-05	1.265E-04	1.323E-05	1.272E-04	2.074E-04	1.496E-04	5.039E+03
Cs134	3.140E-01	8.700E-02	2.028E-01	2.298E-02	1.254E-01	1.758E-01	1.403E-01	3.917E+00
Cs135	4.496E-10	4.289E-11	5.554E-11	5.549E-12	1.466E-10	3.125E-10	1.897E-10	4.003E+09
Cs137	1.257E-05	2.949E-06	6.316E-06	6.893E-07	4.723E-06	7.099E-06	5.412E-06	1.306E+05
Cu64	2.289E-02	6.228E-03	1.445E-02	1.654E-03	9.122E-03	1.291E-02	1.023E-02	5.442E+01
Dy159	3.691E-08	6.938E-09	1.301E-08	1.360E-09	1.313E-08	2.145E-08	1.545E-08	4.877E+07
Es252	4.073E-02	1.108E-02	2.551E-02	2.856E-03	1.607E-02	2.268E-02	1.805E-02	3.151E+01
Es253	4.475E-03	2.763E-03	7.128E-03	9.013E-04	1.742E-03	1.891E-03	1.817E-03	9.986E+01
Es254	1.831E-03	1.127E-03	2.900E-03	3.664E-04	7.085E-04	7.710E-04	7.395E-04	2.457E+02
Es254m	2.025E+01	1.251E+01	3.234E+01	4.091E+00	7.913E+00	8.586E+00	8.257E+00	2.200E-02
Eu149	6.446E-04	1.427E-04	2.945E-04	3.172E-05	2.374E-04	3.645E-04	2.741E-04	2.792E+03
Eu150	3.504E-01	1.074E-01	2.641E-01	3.099E-02	1.475E-01	1.988E-01	1.625E-01	2.904E+00
Eu152	7.590E-01	2.432E-01	6.088E-01	7.208E-02	3.262E-01	4.316E-01	3.569E-01	1.249E+00
Eu154	7.919E-01	2.502E-01	6.244E-01	7.340E-02	3.381E-01	4.502E-01	3.708E-01	1.226E+00
Eu155	3.927E-07	3.715E-08	4.781E-08	4.774E-09	1.279E-07	2.734E-07	1.657E-07	4.584E+06
Fe55	2.370E-15	2.241E-16	2.883E-16	2.879E-17	7.721E-16	1.650E-15	1.000E-15	7.594E+14
Fe59	9.927E-01	3.152E-01	7.877E-01	9.255E-02	4.244E-01	5.649E-01	4.654E-01	9.724E-01
Fr221	5.196E-04	2.885E-04	7.254E-04	9.085E-05	1.942E-04	2.263E-04	2.062E-04	9.906E+02
Fr223	2.028E-03	5.438E-04	1.244E-03	1.392E-04	7.961E-04	1.132E-03	8.964E-04	6.466E+02
Gd152	2.278E-07	1.352E-07	3.544E-07	4.481E-08	9.399E-08	1.024E-07	9.730E-08	2.008E+06
Gd153	3.916E-07	3.703E-08	4.763E-08	4.756E-09	1.276E-07	2.727E-07	1.653E-07	4.596E+06
Hf175	3.258E-03	6.199E-04	1.170E-03	1.225E-04	1.162E-03	1.888E-03	1.365E-03	5.525E+02
Hf181	1.278E-02	2.734E-03	5.504E-03	5.817E-04	4.652E-03	7.211E-03	5.398E-03	1.408E+02
Hg203	2.883E-04	4.448E-05	7.450E-05	7.612E-06	9.918E-05	1.754E-04	1.200E-04	6.245E+03
Ho166m	3.505E-01	9.769E-02	2.279E-01	2.581E-02	1.399E-01	1.960E-01	1.567E-01	3.487E+00
I129	5.072E-11	4.796E-12	6.169E-12	6.160E-13	1.652E-11	3.531E-11	2.141E-11	3.549E+10
I131	1.112E-02	2.624E-03	5.627E-03	6.108E-04	4.180E-03	6.259E-03	4.780E-03	1.474E+02
In113m	2.324E-03	4.383E-04	8.233E-04	8.609E-05	8.274E-04	1.349E-03	9.731E-04	7.744E+02
In114	4.578E-03	1.369E-03	3.330E-03	3.865E-04	1.901E-03	2.592E-03	2.104E-03	2.329E+02
In114m	6.465E-03	1.677E-03	3.771E-03	4.175E-04	2.502E-03	3.596E-03	2.830E-03	2.156E+02
In115	1.424E-06	2.627E-07	4.897E-07	5.112E-08	5.049E-07	8.332E-07	5.965E-07	1.264E+06
In115m	1.658E-03	3.128E-04	5.877E-04	6.146E-05	5.902E-04	9.622E-04	6.940E-04	1.086E+03
Ir194	3.060E-02	9.721E-03	2.432E-02	2.887E-03	1.314E-02	1.743E-02	1.438E-02	3.118E+01

Table 7.5-4 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
K40	1.912E-01	6.397E-02	1.632E-01	1.961E-02	8.422E-02	1.093E-01	9.147E-02	4.589E+00
K42	6.068E-01	2.139E-01	5.618E-01	6.888E-02	2.778E-01	3.501E-01	2.978E-01	1.307E+00
Kr85	1.907E-04	4.426E-05	9.348E-05	1.013E-05	7.098E-05	1.068E-04	8.146E-05	8.885E+03
La140	3.541E+00	1.258E+00	3.320E+00	4.092E-01	1.628E+00	2.048E+00	1.746E+00	2.199E-01
Lu177	4.613E-05	7.404E-06	1.273E-05	1.308E-06	1.597E-05	2.785E-05	1.922E-05	3.902E+04
Lu177m	3.207E-03	6.760E-04	1.352E-03	1.428E-04	1.164E-03	1.817E-03	1.353E-03	5.613E+02
Mn54	2.642E-01	7.397E-02	1.725E-01	1.953E-02	1.055E-01	1.477E-01	1.181E-01	4.608E+00
Na22	1.292E+00	4.110E-01	1.031E+00	1.214E-01	5.538E-01	7.363E-01	6.073E-01	7.415E-01
Na24	1.204E+01	4.607E+00	1.263E+01	1.617E+00	5.788E+00	7.118E+00	6.180E+00	5.568E-02
Nb91	1.267E-04	2.971E-05	6.305E-05	6.843E-06	4.728E-05	7.081E-05	5.418E-05	1.315E+04
Nb94	4.228E-01	1.161E-01	2.684E-01	3.019E-02	1.674E-01	2.358E-01	1.879E-01	2.981E+00
Nb95	1.588E-01	4.220E-02	9.605E-02	1.068E-02	6.200E-02	8.819E-02	6.989E-02	8.429E+00
Nb95m	1.374E-04	2.525E-05	4.789E-05	5.077E-06	4.888E-05	8.150E-05	5.797E-05	1.310E+04
Nd144	5.907E-08	3.057E-08	8.108E-08	1.030E-08	2.564E-08	2.946E-08	2.692E-08	8.739E+06
Ni59	2.986E-08	7.001E-09	1.486E-08	1.613E-09	1.114E-08	1.669E-08	1.277E-08	5.580E+07
Np235	1.306E-08	3.933E-09	9.070E-09	1.118E-09	4.514E-09	7.608E-09	5.357E-09	8.047E+07
Np237	1.633E-04	9.984E-05	2.538E-04	3.200E-05	6.137E-05	6.723E-05	6.411E-05	2.813E+03
Np238	3.471E-01	1.055E-01	2.571E-01	2.979E-02	1.447E-01	1.960E-01	1.597E-01	3.021E+00
Np239	2.479E-04	4.307E-05	7.759E-05	8.049E-06	8.697E-05	1.470E-04	1.036E-04	7.261E+03
Np240	2.960E-01	8.480E-02	2.004E-01	2.282E-02	1.197E-01	1.659E-01	1.333E-01	3.944E+00
Np240m	1.152E-01	3.679E-02	9.233E-02	1.101E-02	4.970E-02	6.564E-02	5.428E-02	8.178E+00
Os185	9.201E-02	2.388E-02	5.356E-02	5.915E-03	3.561E-02	5.131E-02	4.021E-02	1.522E+01
Os194	2.141E-17	2.025E-18	2.605E-18	2.601E-19	6.975E-18	1.491E-17	9.038E-18	8.406E+16
P32	1.578E-03	4.314E-04	1.001E-03	1.133E-04	6.276E-04	8.871E-04	7.037E-04	7.941E+02
P33	4.211E-09	5.681E-10	9.019E-10	9.179E-11	1.424E-09	2.684E-09	1.761E-09	4.274E+08
Pa231	4.807E-04	1.713E-04	3.994E-04	4.811E-05	1.751E-04	2.469E-04	1.964E-04	1.871E+03
Pa233	2.131E-03	4.087E-04	7.754E-04	8.121E-05	7.609E-04	1.233E-03	8.933E-04	8.446E+02
Pa234	6.224E-01	1.938E-01	4.794E-01	5.648E-02	2.639E-01	3.525E-01	2.897E-01	1.594E+00
Pa234m	1.710E-02	5.400E-03	1.347E-02	1.595E-03	7.312E-03	9.723E-03	8.010E-03	5.642E+01
Pb209	6.432E-06	1.276E-06	2.480E-06	2.613E-07	2.311E-06	3.704E-06	2.706E-06	2.799E+05
Pb210	7.521E-13	4.639E-13	1.188E-12	1.505E-13	2.874E-13	3.152E-13	3.031E-13	5.978E+11
Pb211	1.380E-02	3.819E-03	8.874E-03	1.004E-03	5.493E-03	7.723E-03	6.157E-03	8.967E+01
Pb212	2.754E-04	4.670E-05	8.294E-05	8.579E-06	9.622E-05	1.642E-04	1.149E-04	6.536E+03
Pb214	5.031E-03	1.233E-03	2.706E-03	2.990E-04	1.921E-03	2.840E-03	2.189E-03	3.010E+02
Pm145	6.965E-17	2.606E-17	7.058E-17	9.022E-18	3.311E-17	4.102E-17	3.542E-17	9.976E+15
Pm146	1.012E-01	2.637E-02	5.943E-02	6.582E-03	3.924E-02	5.629E-02	4.435E-02	1.367E+01
Pm147	1.059E-09	1.179E-10	1.696E-10	1.712E-11	3.503E-10	7.109E-10	4.451E-10	1.700E+09
Pm148	4.680E-01	1.535E-01	3.883E-01	4.641E-02	2.039E-01	2.668E-01	2.222E-01	1.939E+00
Pm148m	4.067E-01	1.147E-01	2.697E-01	3.069E-02	1.637E-01	2.285E-01	1.827E-01	2.933E+00
Po209	1.244E-03	3.481E-04	8.114E-04	9.189E-05	4.965E-04	6.954E-04	5.559E-04	9.794E+02
Po210	2.483E-04	1.518E-04	3.861E-04	4.865E-05	9.351E-05	1.023E-04	9.763E-05	1.850E+03
Po211	2.169E-03	7.618E-04	1.830E-03	2.166E-04	8.496E-04	1.140E-03	9.391E-04	4.156E+02
Po212	4.906E-04	3.016E-04	7.678E-04	9.669E-05	1.850E-04	2.017E-04	1.930E-04	9.308E+02
Po213	4.982E-04	3.036E-04	7.724E-04	9.721E-05	1.880E-04	2.059E-04	1.963E-04	9.259E+02

Table 7.5-4 – [redacted]SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side(1)	Top	Bottom	Side	
Po214	5.071E-04	3.060E-04	7.777E-04	9.780E-05	1.914E-04	2.108E-04	2.002E-04	9.202E+02
Po215	5.073E-04	3.056E-04	7.764E-04	9.765E-05	1.913E-04	2.110E-04	2.002E-04	9.217E+02
Po216	4.956E-04	3.030E-04	7.710E-04	9.707E-05	1.870E-04	2.045E-04	1.952E-04	9.272E+02
Po218	3.813E-04	2.335E-04	5.940E-04	7.482E-05	1.436E-04	1.570E-04	1.499E-04	1.203E+03
Pr143	5.767E-05	1.294E-05	2.696E-05	2.904E-06	2.134E-05	3.260E-05	2.460E-05	3.099E+04
Pr144	7.418E-02	2.671E-02	7.076E-02	8.848E-03	3.446E-02	4.321E-02	3.698E-02	1.017E+01
Pr144m	1.944E-03	6.796E-04	1.779E-03	2.185E-04	8.850E-04	1.120E-03	9.509E-04	4.119E+02
Pu236	3.642E-04	2.239E-04	5.701E-04	7.185E-05	1.374E-04	1.499E-04	1.433E-04	1.253E+03
Pu238	3.290E-04	2.024E-04	5.158E-04	6.503E-05	1.243E-04	1.356E-04	1.297E-04	1.384E+03
Pu239	2.177E-04	1.337E-04	3.401E-04	4.287E-05	8.189E-05	8.941E-05	8.545E-05	2.099E+03
Pu240	1.730E-03	1.066E-03	2.739E-03	3.459E-04	6.668E-04	7.252E-04	6.962E-04	2.602E+02
Pu241	4.541E-09	2.787E-09	7.090E-09	8.939E-10	1.708E-09	1.866E-09	1.783E-09	1.007E+08
Pu242	1.452E-01	8.953E-02	2.303E-01	2.908E-02	5.614E-02	6.104E-02	5.863E-02	3.095E+00
Pu243	3.195E-05	6.087E-06	1.151E-05	1.205E-06	1.139E-05	1.851E-05	1.339E-05	5.634E+04
Pu244	3.360E+01	2.073E+01	5.337E+01	6.743E+00	1.302E+01	1.415E+01	1.360E+01	1.335E-02
Pu246	8.562E-05	1.315E-05	2.200E-05	2.247E-06	2.944E-05	5.220E-05	3.565E-05	2.102E+04
Ra223	9.853E-04	3.300E-04	7.614E-04	9.049E-05	3.609E-04	5.138E-04	4.065E-04	9.946E+02
Ra224	3.316E-04	1.956E-04	4.951E-04	6.227E-05	1.243E-04	1.397E-04	1.307E-04	1.445E+03
Ra225	8.277E-08	1.395E-08	2.479E-08	2.566E-09	2.890E-08	4.954E-08	3.457E-08	2.175E+07
Ra226	1.713E-04	1.052E-04	2.675E-04	3.373E-05	6.445E-05	7.037E-05	6.727E-05	2.668E+03
Rb86	7.304E-02	2.265E-02	5.582E-02	6.519E-03	3.080E-02	4.140E-02	3.388E-02	1.381E+01
Rb87	1.064E-08	1.586E-09	2.648E-09	2.713E-10	3.646E-09	6.591E-09	4.443E-09	1.692E+08
Re188	1.875E-02	5.944E-03	1.487E-02	1.769E-03	8.052E-03	1.067E-02	8.808E-03	5.087E+01
Rh102	7.464E-02	2.176E-02	5.229E-02	6.069E-03	3.070E-02	4.227E-02	3.406E-02	1.483E+01
Rh106	8.936E-02	2.852E-02	7.175E-02	8.616E-03	3.861E-02	5.110E-02	4.222E-02	1.045E+01
Rn219	1.554E-03	5.288E-04	1.226E-03	1.451E-04	5.723E-04	8.027E-04	6.426E-04	6.201E+02
Rn220	4.882E-04	2.827E-04	7.148E-04	8.964E-05	1.838E-04	2.074E-04	1.935E-04	1.004E+03
Rn222	3.096E-04	1.788E-04	4.518E-04	5.667E-05	1.164E-04	1.317E-04	1.226E-04	1.588E+03
Ru103	1.802E-02	4.009E-03	8.260E-03	8.794E-04	6.627E-03	1.013E-02	7.648E-03	9.991E+01
S35	1.483E-10	1.402E-11	1.804E-11	1.801E-12	4.830E-11	1.032E-10	6.259E-11	1.214E+10
Sb124	2.182E+00	7.688E-01	2.019E+00	2.484E-01	9.994E-01	1.261E+00	1.073E+00	3.623E-01
Sb125	3.140E-02	7.576E-03	1.633E-02	1.765E-03	1.183E-02	1.753E-02	1.349E-02	5.099E+01
Sb126	4.261E-01	1.138E-01	2.601E-01	2.910E-02	1.670E-01	2.380E-01	1.879E-01	3.093E+00
Sb126m	1.769E-01	4.564E-02	1.024E-01	1.135E-02	6.837E-02	9.881E-02	7.723E-02	7.931E+00
Sc46	1.088E+00	3.300E-01	8.042E-01	9.334E-02	4.532E-01	6.145E-01	5.003E-01	9.642E-01
Se75	2.067E-03	4.248E-04	8.397E-04	8.847E-05	7.465E-04	1.179E-03	8.714E-04	8.706E+02
Se79	1.734E-10	1.639E-11	2.109E-11	2.106E-12	5.647E-11	1.207E-10	7.318E-11	1.038E+10
Sm145	4.947E-07	1.062E-07	2.139E-07	2.261E-08	1.801E-07	2.788E-07	2.090E-07	3.638E+06
Sm146	1.056E-06	6.478E-07	1.687E-06	2.132E-07	4.253E-07	4.596E-07	4.420E-07	4.222E+05
Sm147	5.116E-07	3.109E-07	8.106E-07	1.024E-07	2.076E-07	2.241E-07	2.147E-07	8.788E+05
Sm148	9.382E-08	5.228E-08	1.379E-07	1.748E-08	3.969E-08	4.448E-08	4.142E-08	5.149E+06
Sn113	8.143E-06	1.320E-06	2.298E-06	2.371E-07	2.826E-06	4.921E-06	3.400E-06	2.211E+05
Sn123	5.830E-03	1.782E-03	4.363E-03	5.079E-04	2.442E-03	3.302E-03	2.692E-03	1.772E+02
Sn126	1.219E-07	2.071E-08	3.693E-08	3.825E-09	4.261E-08	7.281E-08	5.092E-08	1.477E+07

Table 7.5-4 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side(1)	Top	Bottom	Side	
Sr85	3.865E-02	9.064E-03	1.924E-02	2.088E-03	1.442E-02	2.160E-02	1.653E-02	4.310E+01
Sr89	9.004E-04	2.383E-04	5.435E-04	6.097E-05	3.531E-04	5.056E-04	3.978E-04	1.476E+03
Sr90	4.136E-06	7.896E-07	1.500E-06	1.571E-07	1.475E-06	2.401E-06	1.735E-06	4.352E+05
Ta182	9.926E-01	3.152E-01	7.878E-01	9.258E-02	4.244E-01	5.648E-01	4.654E-01	9.722E-01
Tb160	5.230E-01	1.588E-01	3.872E-01	4.489E-02	2.180E-01	2.954E-01	2.407E-01	2.005E+00
Tc99	2.444E-08	3.888E-09	6.712E-09	6.915E-10	8.457E-09	1.487E-08	1.021E-08	7.364E+07
Tc99m	1.652E-06	1.565E-07	2.017E-07	2.015E-08	5.382E-07	1.150E-06	6.972E-07	1.090E+06
Te121	3.979E-02	9.325E-03	1.979E-02	2.147E-03	1.485E-02	2.224E-02	1.701E-02	4.191E+01
Te121m	2.184E-02	6.736E-03	1.657E-02	1.933E-03	9.192E-03	1.239E-02	1.012E-02	4.655E+01
Te123m	1.557E-06	1.473E-07	1.896E-07	1.893E-08	5.073E-07	1.084E-06	6.573E-07	1.156E+06
Te125m	5.185E-09	4.903E-10	6.307E-10	6.297E-11	1.689E-09	3.610E-09	2.188E-09	3.472E+08
Te127	1.632E-04	3.475E-05	6.979E-05	7.374E-06	5.933E-05	9.216E-05	6.889E-05	1.103E+04
Te127m	9.831E-06	2.421E-06	5.276E-06	5.722E-07	3.728E-06	5.480E-06	4.236E-06	1.573E+05
Te129	8.912E-03	2.580E-03	6.167E-03	7.100E-04	3.643E-03	5.039E-03	4.050E-03	1.268E+02
Te129m	4.808E-03	1.261E-03	2.850E-03	3.172E-04	1.865E-03	2.677E-03	2.105E-03	2.837E+02
Th227	8.482E-04	2.750E-04	6.296E-04	7.509E-05	3.084E-04	4.497E-04	3.496E-04	1.199E+03
Th228	2.630E-04	1.613E-04	4.102E-04	5.170E-05	9.894E-05	1.082E-04	1.033E-04	1.741E+03
Th229	2.096E-04	1.166E-04	2.931E-04	3.676E-05	7.816E-05	9.109E-05	8.299E-05	2.449E+03
Th230	1.583E-04	9.734E-05	2.476E-04	3.123E-05	5.955E-05	6.495E-05	6.214E-05	2.882E+03
Th231	3.648E-07	5.975E-08	1.047E-07	1.081E-08	1.268E-07	2.202E-07	1.524E-07	4.934E+06
Th232	7.422E-05	4.571E-05	1.166E-04	1.475E-05	2.813E-05	3.073E-05	2.949E-05	6.102E+03
Th234	4.728E-09	4.471E-10	5.751E-10	5.743E-11	1.540E-09	3.292E-09	1.996E-09	3.807E+08
Tl206	1.322E-05	3.700E-06	8.627E-06	9.771E-07	5.278E-06	7.390E-06	5.909E-06	9.211E+04
Tl207	1.185E-03	3.204E-04	7.362E-04	8.284E-05	4.672E-04	6.634E-04	5.254E-04	1.086E+03
Tl208	1.031E+01	4.022E+00	1.113E+01	1.435E+00	5.022E+00	6.130E+00	5.350E+00	6.271E-02
Tl209	3.126E+00	1.103E+00	2.898E+00	3.553E-01	1.432E+00	1.804E+00	1.535E+00	2.533E-01
Tm168	2.885E-01	8.100E-02	1.896E-01	2.151E-02	1.156E-01	1.615E-01	1.292E-01	4.185E+00
Tm170	6.174E-05	1.395E-05	2.918E-05	3.148E-06	2.289E-05	3.488E-05	2.636E-05	2.859E+04
Tm171	1.418E-17	1.341E-18	1.725E-18	1.722E-19	4.619E-18	9.873E-18	5.985E-18	1.269E+17
U232	2.442E-04	1.502E-04	3.821E-04	4.816E-05	9.189E-05	1.003E-04	9.587E-05	1.869E+03
U233	1.755E-04	1.077E-04	2.740E-04	3.454E-05	6.602E-05	7.212E-05	6.891E-05	2.606E+03
U234	1.698E-04	1.044E-04	2.656E-04	3.349E-05	6.387E-05	6.965E-05	6.663E-05	2.687E+03
U235	1.401E-04	7.306E-05	1.822E-04	2.282E-05	5.194E-05	6.328E-05	5.585E-05	3.944E+03
U236	1.515E-04	9.326E-05	2.377E-04	3.000E-05	5.733E-05	6.247E-05	5.984E-05	3.000E+03
U237	1.306E-04	2.190E-05	3.866E-05	3.995E-06	4.554E-05	7.807E-05	5.449E-05	1.379E+04
U238	1.326E-02	8.185E-03	2.108E-02	2.664E-03	5.145E-03	5.593E-03	5.374E-03	3.378E+01
U239	2.708E-03	7.494E-04	1.740E-03	1.963E-04	1.078E-03	1.515E-03	1.207E-03	4.586E+02
U240	2.744E-07	4.401E-08	7.599E-08	7.823E-09	9.502E-08	1.662E-07	1.145E-07	6.560E+06
W181	2.113E-09	1.998E-10	2.570E-10	2.566E-11	6.882E-10	1.471E-09	8.918E-10	8.519E+08
W185	5.495E-07	9.801E-08	1.793E-07	1.866E-08	1.937E-07	3.241E-07	2.298E-07	3.275E+06
W188	2.341E-06	3.629E-07	6.098E-07	6.236E-08	8.060E-07	1.424E-06	9.747E-07	7.689E+05
Xe127	8.724E-04	1.568E-04	2.876E-04	2.995E-05	3.079E-04	5.131E-04	3.648E-04	2.063E+03
Xe131m	3.596E-08	3.400E-09	4.373E-09	4.367E-10	1.171E-08	2.503E-08	1.518E-08	5.006E+07
Y88	4.432E+00	1.586E+00	4.190E+00	5.222E-01	2.043E+00	2.563E+00	2.192E+00	1.724E-01

Table 7.5-4 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Y89m	4.037E-01	1.177E-01	2.802E-01	3.195E-02	1.645E-01	2.261E-01	1.826E-01	2.817E+00
Y90	6.644E-03	1.986E-03	4.827E-03	5.623E-04	2.762E-03	3.760E-03	3.053E-03	1.600E+02
Y90m	1.406E-02	3.006E-03	6.053E-03	6.399E-04	5.115E-03	7.935E-03	5.938E-03	1.280E+02
Y91	4.221E-03	1.306E-03	3.232E-03	3.779E-04	1.784E-03	2.400E-03	1.964E-03	2.381E+02
Zn65	4.132E-01	1.284E-01	3.167E-01	3.700E-02	1.744E-01	2.343E-01	1.918E-01	2.432E+00
Zr88	3.507E-03	6.613E-04	1.242E-03	1.299E-04	1.249E-03	2.036E-03	1.468E-03	5.133E+02
Zr90m	7.151E+00	2.722E+00	7.375E+00	9.389E-01	3.445E+00	4.211E+00	3.664E+00	9.586E-02
Zr95	1.569E-01	4.171E-02	9.494E-02	1.055E-02	6.128E-02	8.717E-02	6.908E-02	8.528E+00

Notes:

[1] The dose rate at 1-meter from the side of the package bounds the dose rate at 1-meter from the top and bottom of the package based on inspection of the package surface dose rates. Therefore, 1-meter dose rates on the ends of the package are not reported.

Table 7.5-5 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Ac225	2.378E-04	2.064E-04	4.886E-04	1.126E-04	1.450E-05	3.928E-06	1.508E-04	1.751E-04	1.600E-04	3.684E+03	4.583E+03
Ac227	1.847E-06	1.593E-06	3.792E-06	8.762E-07	1.129E-07	3.050E-08	1.036E-06	1.152E-06	1.086E-06	4.747E+05	5.902E+05
Ac228	6.468E-02	7.920E-02	1.464E-01	3.175E-02	4.148E-03	1.164E-03	2.282E-01	2.996E-01	2.487E-01	1.230E+01	1.547E+01
Ag108	1.908E-04	2.770E-04	4.284E-04	8.735E-05	1.113E-05	2.924E-06	1.193E-03	1.720E-03	1.347E-03	4.202E+03	5.232E+03
Ag108m	1.290E-02	1.926E-02	2.885E-02	5.784E-03	7.300E-04	2.017E-04	8.525E-02	1.229E-01	9.645E-02	6.240E+01	7.320E+01
Ag110	2.266E-03	2.828E-03	5.116E-03	1.107E-03	1.462E-04	4.020E-05	8.711E-03	1.171E-02	9.580E-03	3.519E+02	4.478E+02
Ag110m	1.801E-01	2.224E-01	4.073E-01	8.838E-02	1.165E-02	3.212E-03	6.445E-01	8.497E-01	7.037E-01	4.419E+00	5.604E+00
Am241	1.943E-04	1.670E-04	3.988E-04	9.209E-05	1.187E-05	3.212E-06	1.043E-04	1.139E-04	1.089E-04	4.514E+03	5.604E+03
Am242	1.038E-07	1.879E-07	2.268E-07	4.401E-08	5.198E-09	1.427E-09	1.479E-06	2.401E-06	1.739E-06	3.749E+06	3.749E+06
Am242m	1.687E-06	1.451E-06	3.479E-06	8.045E-07	1.039E-07	2.812E-08	9.193E-07	1.005E-06	9.604E-07	5.174E+05	6.400E+05
Am243	1.679E-04	1.444E-04	3.446E-04	7.960E-05	1.026E-05	2.774E-06	9.025E-05	9.860E-05	9.418E-05	5.224E+03	6.488E+03
Am245	1.426E-06	2.518E-06	3.132E-06	6.120E-07	7.409E-08	1.998E-08	1.985E-05	3.247E-05	2.339E-05	2.772E+05	2.772E+05
Am246	6.554E-03	9.711E-03	1.471E-02	2.967E-03	3.754E-04	9.866E-05	4.173E-02	6.000E-02	4.714E-02	1.224E+02	1.500E+02
At217	3.447E-04	2.967E-04	7.080E-04	1.633E-04	2.107E-05	5.711E-06	1.899E-04	2.088E-04	1.985E-04	2.542E+03	3.152E+03
Au198	6.332E-04	1.029E-03	1.400E-03	2.790E-04	3.345E-05	9.081E-06	6.009E-03	9.164E-03	6.930E-03	9.821E+02	9.821E+02
Ba133	6.891E-05	1.319E-04	1.489E-04	2.860E-05	3.357E-06	9.323E-07	1.156E-03	1.886E-03	1.359E-03	4.773E+03	4.773E+03
Ba137m	3.173E-03	4.937E-03	7.128E-03	1.410E-03	1.801E-04	4.506E-05	2.395E-02	3.513E-02	2.719E-02	2.525E+02	2.562E+02
Ba140	4.515E-04	7.370E-04	1.002E-03	1.969E-04	2.393E-05	6.471E-06	4.027E-03	6.053E-03	4.621E-03	1.487E+03	1.487E+03
Be10	8.660E-08	1.613E-07	1.882E-07	3.636E-08	4.265E-09	1.179E-09	1.347E-06	2.194E-06	1.586E-06	4.101E+06	4.101E+06
Bi207	1.010E-01	1.262E-01	2.278E-01	4.894E-02	6.340E-03	1.716E-03	3.729E-01	4.946E-01	4.079E-01	7.901E+00	1.049E+01
Bi210	8.349E-06	1.284E-05	1.864E-05	3.735E-06	4.646E-07	1.251E-07	6.415E-05	9.538E-05	7.326E-05	9.436E+04	9.436E+04
Bi211	3.474E-04	3.091E-04	7.145E-04	1.640E-04	2.111E-05	5.725E-06	3.485E-04	4.703E-04	3.857E-04	2.519E+03	3.144E+03
Bi212	1.122E-02	1.331E-02	2.540E-02	5.565E-03	7.367E-04	2.075E-04	3.574E-02	4.607E-02	3.867E-02	7.088E+01	8.673E+01
Bi213	5.505E-04	7.736E-04	1.232E-03	2.553E-04	3.203E-05	8.536E-06	3.229E-03	4.660E-03	3.647E-03	1.461E+03	1.931E+03
Bi214	3.144E-01	3.607E-01	7.113E-01	1.592E-01	2.139E-02	6.019E-03	8.892E-01	1.123E+00	9.554E-01	2.531E+00	2.991E+00
Bk247	1.167E-06	2.639E-06	2.469E-06	4.655E-07	5.438E-08	1.480E-08	3.662E-05	6.483E-05	4.432E-05	1.388E+05	1.388E+05
Bk249	1.483E-05	1.275E-05	3.070E-05	7.102E-06	9.193E-07	2.489E-07	8.098E-06	8.803E-06	8.455E-06	5.864E+04	7.232E+04
Bk250	5.241E-02	6.841E-02	1.180E-01	2.489E-02	3.152E-03	8.479E-04	2.210E-01	2.991E-01	2.438E-01	1.526E+01	2.123E+01
C14	2.430E-13	7.762E-13	4.739E-13	8.816E-14	1.047E-14	2.828E-15	3.284E-11	7.020E-11	4.256E-11	1.282E+11	1.282E+11
Ca45	5.167E-11	1.188E-10	1.089E-10	2.054E-11	2.403E-12	6.548E-13	1.939E-09	3.604E-09	2.386E-09	2.497E+09	2.497E+09
Cd113	8.784E-10	1.809E-09	1.881E-09	3.587E-10	4.203E-11	1.158E-11	2.057E-08	3.555E-08	2.468E-08	2.532E+08	2.532E+08

Table 7.5-5 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Cd113m	9.860E-08	1.822E-07	2.146E-07	4.151E-08	4.876E-09	1.346E-09	1.492E-06	2.422E-06	1.754E-06	3.716E+06	3.716E+06
Cd115m	2.201E-03	2.819E-03	4.962E-03	1.051E-03	1.391E-04	3.827E-05	8.896E-03	1.198E-02	9.801E-03	3.628E+02	4.703E+02
Ce141	3.665E-08	7.147E-08	7.912E-08	1.524E-08	1.790E-09	4.941E-10	8.417E-07	1.523E-06	1.026E-06	5.910E+06	5.910E+06
Ce144	1.019E-09	2.665E-09	2.087E-09	3.933E-10	4.637E-11	1.266E-11	7.944E-08	1.648E-07	1.018E-07	5.463E+07	5.463E+07
Cf249	4.438E-04	4.477E-04	9.214E-04	2.077E-04	2.653E-05	7.205E-06	1.255E-03	1.936E-03	1.449E-03	1.953E+03	2.498E+03
Cf250	2.204E+01	1.895E+01	4.582E+01	1.062E+01	1.377E+00	3.730E-01	1.209E+01	1.311E+01	1.261E+01	3.928E-02	4.826E-02
Cf251	2.362E-04	2.036E-04	4.849E-04	1.119E-04	1.442E-05	3.906E-06	1.393E-04	1.606E-04	1.475E-04	3.712E+03	4.608E+03
Cf252	1.013E+03	8.710E+02	2.095E+03	4.846E+02	6.270E+01	1.698E+01	5.533E+02	6.014E+02	5.775E+02	8.590E-04	1.060E-03
Cf253	8.151E-07	7.008E-07	1.673E-06	3.862E-07	4.979E-08	1.349E-08	4.431E-07	4.875E-07	4.633E-07	1.076E+06	1.334E+06
Cf254	3.144E+04	2.704E+04	6.538E+04	1.515E+04	1.965E+03	5.321E+02	1.725E+04	1.871E+04	1.799E+04	2.753E-05	3.383E-05
Cl36	8.964E-07	1.509E-06	1.981E-06	3.879E-07	4.679E-08	1.268E-08	9.308E-06	1.437E-05	1.077E-05	6.264E+05	6.264E+05
Cm240	1.120E-03	9.629E-04	2.312E-03	5.343E-04	6.906E-05	1.871E-05	6.088E-04	6.622E-04	6.353E-04	7.786E+02	9.620E+02
Cm242	1.669E-03	1.435E-03	3.449E-03	7.977E-04	1.032E-04	2.794E-05	9.088E-04	9.886E-04	9.488E-04	5.219E+02	6.442E+02
Cm243	2.407E-04	2.085E-04	4.942E-04	1.140E-04	1.469E-05	3.978E-06	1.644E-04	2.037E-04	1.775E-04	3.642E+03	4.524E+03
Cm244	3.217E-02	2.767E-02	6.658E-02	1.540E-02	1.994E-03	5.399E-04	1.757E-02	1.910E-02	1.834E-02	2.703E+01	3.334E+01
Cm245	3.304E-04	2.841E-04	6.807E-04	1.573E-04	2.032E-05	5.499E-06	1.788E-04	1.951E-04	1.867E-04	2.644E+03	3.273E+03
Cm246	7.232E+00	6.219E+00	1.497E+01	3.464E+00	4.484E-01	1.214E-01	3.949E+00	4.293E+00	4.123E+00	1.202E-01	1.483E-01
Cm247	4.781E-04	7.123E-04	1.031E-03	2.111E-04	2.542E-05	6.972E-06	3.987E-03	6.141E-03	4.617E-03	1.466E+03	1.466E+03
Cm248	2.249E+03	1.934E+03	4.656E+03	1.078E+03	1.395E+02	3.777E+01	1.228E+03	1.335E+03	1.282E+03	3.866E-04	4.766E-04
Cm249	8.305E-05	1.306E-04	1.861E-04	3.675E-05	4.646E-06	1.182E-06	6.524E-04	9.633E-04	7.426E-04	9.343E+03	9.343E+03
Cm250	3.936E+00	4.225E+00	8.924E+00	2.077E+00	2.854E-01	8.105E-02	9.081E+00	1.118E+01	9.693E+00	2.017E-01	2.221E-01
Co57	7.707E-06	1.181E-05	1.725E-05	3.453E-06	4.340E-07	1.092E-07	5.526E-05	8.111E-05	6.282E-05	1.044E+05	1.110E+05
Co58	2.286E-02	3.176E-02	5.173E-02	1.068E-02	1.372E-03	3.629E-04	1.176E-01	1.640E-01	1.314E-01	3.479E+01	4.960E+01
Co60	2.340E-01	2.941E-01	5.275E-01	1.123E-01	1.504E-02	4.067E-03	8.738E-01	1.162E+00	9.578E-01	3.412E+00	4.426E+00
Cr51	7.612E-06	1.456E-05	1.645E-05	3.160E-06	3.710E-07	1.030E-07	1.272E-04	2.074E-04	1.496E-04	4.339E+04	4.339E+04
Cs134	2.400E-02	3.319E-02	5.390E-02	1.119E-02	1.441E-03	3.922E-04	1.254E-01	1.758E-01	1.403E-01	3.340E+01	4.590E+01
Cs135	1.137E-12	3.568E-12	2.228E-12	4.149E-13	4.921E-14	1.330E-14	1.466E-10	3.125E-10	1.897E-10	2.880E+10	2.880E+10
Cs137	5.827E-07	9.049E-07	1.299E-06	2.601E-07	3.228E-08	8.704E-09	4.723E-06	7.099E-06	5.412E-06	1.268E+06	1.268E+06
Cu64	1.761E-03	2.396E-03	3.953E-03	8.355E-04	1.081E-04	2.937E-05	9.122E-03	1.291E-02	1.023E-02	4.554E+02	6.129E+02
Dy159	7.798E-10	1.494E-09	1.685E-09	3.237E-10	3.799E-11	1.055E-11	1.313E-08	2.145E-08	1.545E-08	4.197E+08	4.197E+08
Es252	2.826E-03	4.037E-03	6.333E-03	1.290E-03	1.621E-04	4.562E-05	1.607E-02	2.268E-02	1.805E-02	2.842E+02	3.946E+02

Table 7.5-5 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Es253	3.180E-03	2.734E-03	6.603E-03	1.530E-03	1.983E-04	5.369E-05	1.742E-03	1.891E-03	1.817E-03	2.726E+02	3.353E+02
Es254	1.294E-03	1.113E-03	2.682E-03	6.209E-04	8.041E-05	2.178E-05	7.085E-04	7.710E-04	7.395E-04	6.712E+02	8.266E+02
Es254m	1.442E+01	1.240E+01	2.997E+01	6.947E+00	9.010E-01	2.440E-01	7.913E+00	8.586E+00	8.257E+00	6.005E-02	7.378E-02
Eu149	2.371E-05	3.959E-05	5.245E-05	1.027E-05	1.245E-06	3.375E-07	2.374E-04	3.645E-04	2.741E-04	2.469E+04	2.469E+04
Eu150	3.719E-02	4.728E-02	8.381E-02	1.795E-02	2.358E-03	6.417E-04	1.475E-01	1.988E-01	1.625E-01	2.148E+01	2.805E+01
Eu152	8.955E-02	1.120E-01	2.019E-01	4.360E-02	5.722E-03	1.551E-03	3.262E-01	4.316E-01	3.569E-01	8.915E+00	1.161E+01
Eu154	8.960E-02	1.126E-01	2.021E-01	4.311E-02	5.772E-03	1.577E-03	3.381E-01	4.502E-01	3.708E-01	8.905E+00	1.142E+01
Eu155	9.493E-10	3.029E-09	1.852E-09	3.445E-10	4.090E-11	1.105E-11	1.279E-07	2.734E-07	1.657E-07	3.292E+07	3.292E+07
Fe55	5.713E-18	1.825E-17	1.114E-17	2.072E-18	2.461E-19	6.649E-20	7.721E-16	1.650E-15	1.000E-15	5.454E+15	5.454E+15
Fe59	1.129E-01	1.423E-01	2.545E-01	5.418E-02	7.219E-03	1.948E-03	4.244E-01	5.649E-01	4.654E-01	7.072E+00	9.242E+00
Fr221	3.156E-04	2.728E-04	6.482E-04	1.494E-04	1.927E-05	5.222E-06	1.942E-04	2.263E-04	2.062E-04	2.777E+03	3.447E+03
Fr223	1.355E-04	1.955E-04	3.044E-04	6.183E-05	7.829E-06	2.146E-06	7.961E-04	1.132E-03	8.964E-04	5.914E+03	7.950E+03
Gd152	1.516E-07	1.308E-07	3.184E-07	7.371E-08	9.560E-09	2.607E-09	9.399E-08	1.024E-07	9.730E-08	5.654E+06	6.905E+06
Gd153	9.438E-10	3.015E-09	1.841E-09	3.424E-10	4.066E-11	1.099E-11	1.276E-07	2.727E-07	1.653E-07	3.301E+07	3.301E+07
Hf175	7.168E-05	1.359E-04	1.551E-04	2.985E-05	3.502E-06	9.721E-07	1.162E-03	1.888E-03	1.365E-03	4.767E+03	4.767E+03
Hf181	4.065E-04	7.064E-04	8.934E-04	1.743E-04	2.039E-05	5.621E-06	4.652E-03	7.211E-03	5.398E-03	1.248E+03	1.248E+03
Hg203	3.170E-06	7.165E-06	6.708E-06	1.264E-06	1.477E-07	4.020E-08	9.918E-05	1.754E-04	1.200E-04	5.130E+04	5.130E+04
Ho166m	2.650E-02	3.705E-02	5.972E-02	1.229E-02	1.578E-03	4.265E-04	1.399E-01	1.960E-01	1.567E-01	3.014E+01	4.221E+01
I129	1.222E-13	3.904E-13	2.384E-13	4.435E-14	5.265E-15	1.423E-15	1.652E-11	3.531E-11	2.141E-11	2.549E+11	2.549E+11
I131	5.111E-04	8.008E-04	1.140E-03	2.263E-04	2.848E-05	7.578E-06	4.180E-03	6.259E-03	4.780E-03	1.438E+03	1.438E+03
In113m	4.953E-05	9.475E-05	1.070E-04	2.056E-05	2.414E-06	6.703E-07	8.274E-04	1.349E-03	9.731E-04	6.670E+03	6.670E+03
In114	4.483E-04	5.800E-04	1.010E-03	2.136E-04	2.837E-05	7.724E-06	1.901E-03	2.592E-03	2.104E-03	1.782E+03	2.331E+03
In114m	3.879E-04	5.755E-04	8.659E-04	1.740E-04	2.184E-05	6.183E-06	2.502E-03	3.596E-03	2.830E-03	2.079E+03	2.503E+03
In115	2.933E-08	5.607E-08	6.349E-08	1.222E-08	1.431E-09	3.961E-10	5.049E-07	8.332E-07	5.965E-07	1.080E+07	1.080E+07
In115m	3.540E-05	6.768E-05	7.650E-05	1.470E-05	1.725E-06	4.791E-07	5.902E-04	9.622E-04	6.940E-04	9.353E+03	9.353E+03
Ir194	3.609E-03	4.469E-03	8.148E-03	1.763E-03	2.313E-04	6.353E-05	1.314E-02	1.743E-02	1.438E-02	2.209E+02	2.833E+02
K40	2.558E-02	3.120E-02	5.773E-02	1.265E-02	1.684E-03	4.583E-04	8.422E-02	1.093E-01	9.147E-02	3.118E+01	3.928E+01
K42	9.540E-02	1.107E-01	2.165E-01	4.786E-02	6.371E-03	1.796E-03	2.778E-01	3.501E-01	2.978E-01	8.314E+00	1.002E+01
Kr85	7.949E-06	1.297E-05	1.765E-05	3.467E-06	4.218E-07	1.140E-07	7.098E-05	1.068E-04	8.146E-05	8.428E+04	8.428E+04
La140	5.754E-01	6.613E-01	1.306E+00	2.908E-01	3.888E-02	1.093E-02	1.628E+00	2.048E+00	1.746E+00	1.378E+00	1.647E+00
Lu177	5.951E-07	1.281E-06	1.267E-06	2.404E-07	2.812E-08	7.702E-09	1.597E-05	2.785E-05	1.922E-05	3.232E+05	3.232E+05

Table 7.5-5 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Lu177m	9.830E-05	1.719E-04	2.158E-04	4.208E-05	4.928E-06	1.361E-06	1.164E-03	1.817E-03	1.353E-03	4.954E+03	4.954E+03
Mn54	1.976E-02	2.792E-02	4.473E-02	9.157E-03	1.173E-03	3.070E-04	1.055E-01	1.477E-01	1.181E-01	4.024E+01	5.863E+01
Na22	1.497E-01	1.867E-01	3.378E-01	7.200E-02	9.874E-03	2.703E-03	5.538E-01	7.363E-01	6.073E-01	5.329E+00	6.658E+00
Na24	2.509E+00	2.719E+00	5.699E+00	1.320E+00	1.814E-01	5.000E-02	5.788E+00	7.118E+00	6.180E+00	3.158E-01	3.600E-01
Nb91	5.423E-06	8.808E-06	1.205E-05	2.368E-06	2.884E-07	7.790E-08	4.728E-05	7.081E-05	5.418E-05	1.271E+05	1.271E+05
Nb94	2.996E-02	4.282E-02	6.752E-02	1.375E-02	1.753E-03	4.724E-04	1.674E-01	2.358E-01	1.879E-01	2.666E+01	3.811E+01
Nb95	1.022E-02	1.492E-02	2.283E-02	4.605E-03	5.807E-04	1.656E-04	6.200E-02	8.819E-02	6.989E-02	7.885E+01	1.020E+02
Nb95m	3.323E-06	5.828E-06	7.292E-06	1.432E-06	1.752E-07	4.857E-08	4.888E-05	8.150E-05	5.797E-05	1.104E+05	1.104E+05
Nd144	2.975E-08	2.664E-08	6.342E-08	1.469E-08	1.924E-09	5.278E-10	2.564E-08	2.946E-08	2.692E-08	2.838E+07	3.411E+07
Ni59	1.278E-09	2.076E-09	2.839E-09	5.580E-10	6.797E-11	1.836E-11	1.114E-08	1.669E-08	1.277E-08	5.393E+08	5.393E+08
Np235	3.663E-09	3.194E-09	7.515E-09	1.735E-09	2.237E-10	6.041E-11	4.514E-09	7.608E-09	5.357E-09	2.395E+08	2.979E+08
Np237	1.139E-04	9.800E-05	2.337E-04	5.405E-05	6.970E-06	1.880E-06	6.137E-05	6.723E-05	6.411E-05	7.703E+03	9.572E+03
Np238	3.428E-02	4.477E-02	7.715E-02	1.627E-02	2.060E-03	5.538E-04	1.447E-01	1.960E-01	1.597E-01	2.333E+01	3.250E+01
Np239	4.203E-06	8.425E-06	9.034E-06	1.728E-06	2.025E-07	5.591E-08	8.697E-05	1.470E-04	1.036E-04	6.122E+04	6.122E+04
Np240	2.429E-02	3.315E-02	5.474E-02	1.137E-02	1.428E-03	3.879E-04	1.197E-01	1.659E-01	1.333E-01	3.288E+01	4.641E+01
Np240m	1.391E-02	1.710E-02	3.144E-02	6.836E-03	9.004E-04	2.496E-04	4.970E-02	6.564E-02	5.428E-02	5.724E+01	7.212E+01
Os185	5.463E-03	8.135E-03	1.231E-02	2.473E-03	3.159E-04	8.146E-05	3.561E-02	5.131E-02	4.021E-02	1.463E+02	1.754E+02
Os194	5.161E-20	1.648E-19	1.007E-19	1.872E-20	2.223E-21	6.007E-22	6.975E-18	1.491E-17	9.038E-18	6.036E+17	6.036E+17
P32	1.174E-04	1.625E-04	2.637E-04	5.465E-05	6.970E-06	1.879E-06	6.276E-04	8.871E-04	7.037E-04	6.827E+03	9.578E+03
P33	3.478E-11	8.144E-11	7.306E-11	1.376E-11	1.610E-12	4.382E-13	1.424E-09	2.684E-09	1.761E-09	3.353E+09	3.353E+09
Pa231	1.387E-04	1.259E-04	2.854E-04	6.543E-05	8.405E-06	2.272E-06	1.751E-04	2.469E-04	1.964E-04	6.308E+03	7.922E+03
Pa233	4.822E-05	9.077E-05	1.045E-04	2.014E-05	2.361E-06	6.551E-07	7.609E-04	1.233E-03	8.933E-04	7.299E+03	7.299E+03
Pa234	6.850E-02	8.628E-02	1.548E-01	3.329E-02	4.342E-03	1.204E-03	2.639E-01	3.525E-01	2.897E-01	1.162E+01	1.495E+01
Pa234m	1.973E-03	2.458E-03	4.455E-03	9.600E-04	1.255E-04	3.451E-05	7.312E-03	9.723E-03	8.010E-03	4.040E+02	5.216E+02
Pb209	1.684E-07	3.034E-07	3.682E-07	7.146E-08	8.442E-09	2.318E-09	2.311E-06	3.704E-06	2.706E-06	2.429E+06	2.429E+06
Pb210	5.349E-13	4.610E-13	1.103E-12	2.562E-13	3.327E-14	8.927E-15	2.874E-13	3.152E-13	3.031E-13	1.633E+12	2.016E+12
Pb211	1.018E-03	1.434E-03	2.297E-03	4.715E-04	6.016E-05	1.596E-05	5.493E-03	7.723E-03	6.157E-03	7.836E+02	1.128E+03
Pb212	4.300E-06	8.804E-06	9.219E-06	1.759E-06	2.060E-07	5.677E-08	9.622E-05	1.642E-04	1.149E-04	5.482E+04	5.482E+04
Pb214	2.686E-04	4.032E-04	6.010E-04	1.212E-04	1.525E-05	4.166E-06	1.921E-03	2.840E-03	2.189E-03	2.995E+03	3.169E+03
Pm145	1.377E-17	1.498E-17	3.122E-17	7.214E-18	9.862E-19	2.795E-19	3.311E-17	4.102E-17	3.542E-17	5.765E+16	6.439E+16
Pm146	6.176E-03	9.109E-03	1.379E-02	2.775E-03	3.488E-04	9.917E-05	3.924E-02	5.629E-02	4.435E-02	1.306E+02	1.599E+02

Table 7.5-5 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Pm147	5.116E-12	1.327E-11	1.052E-11	1.975E-12	2.320E-13	6.297E-14	3.503E-10	7.109E-10	4.451E-10	1.266E+10	1.266E+10
Pm148	5.945E-02	7.316E-02	1.342E-01	2.929E-02	3.878E-03	1.058E-03	2.039E-01	2.668E-01	2.222E-01	1.342E+01	1.701E+01
Pm148m	3.267E-02	4.460E-02	7.340E-02	1.526E-02	1.931E-03	5.178E-04	1.637E-01	2.285E-01	1.827E-01	2.452E+01	3.476E+01
Po209	9.293E-05	1.313E-04	2.104E-04	4.307E-05	5.517E-06	1.444E-06	4.965E-04	6.954E-04	5.559E-04	8.556E+03	1.247E+04
Po210	1.728E-04	1.487E-04	3.547E-04	8.194E-05	1.056E-05	2.856E-06	9.351E-05	1.023E-04	9.763E-05	5.074E+03	6.302E+03
Po211	4.628E-04	4.654E-04	9.750E-04	2.178E-04	2.802E-05	7.535E-06	8.496E-04	1.140E-03	9.391E-04	1.846E+03	2.389E+03
Po212	3.440E-04	2.956E-04	7.065E-04	1.630E-04	2.103E-05	5.699E-06	1.850E-04	2.017E-04	1.930E-04	2.548E+03	3.158E+03
Po213	3.445E-04	2.964E-04	7.076E-04	1.632E-04	2.105E-05	5.707E-06	1.880E-04	2.059E-04	1.963E-04	2.544E+03	3.154E+03
Po214	3.451E-04	2.972E-04	7.088E-04	1.635E-04	2.109E-05	5.717E-06	1.914E-04	2.108E-04	2.002E-04	2.539E+03	3.149E+03
Po215	3.448E-04	2.969E-04	7.083E-04	1.634E-04	2.107E-05	5.712E-06	1.913E-04	2.110E-04	2.002E-04	2.541E+03	3.151E+03
Po216	3.444E-04	2.962E-04	7.073E-04	1.632E-04	2.105E-05	5.705E-06	1.870E-04	2.045E-04	1.952E-04	2.545E+03	3.155E+03
Po218	2.659E-04	2.286E-04	5.458E-04	1.260E-04	1.624E-05	4.400E-06	1.436E-04	1.570E-04	1.499E-04	3.298E+03	4.091E+03
Pr143	2.261E-06	3.684E-06	5.015E-06	9.904E-07	1.214E-07	3.264E-08	2.134E-05	3.260E-05	2.460E-05	2.761E+05	2.761E+05
Pr144	1.297E-02	1.456E-02	2.927E-02	6.660E-03	9.014E-04	2.541E-04	3.446E-02	4.321E-02	3.698E-02	6.149E+01	7.085E+01
Pr144m	3.021E-04	3.504E-04	6.859E-04	1.518E-04	2.031E-05	5.774E-06	8.850E-04	1.120E-03	9.509E-04	2.624E+03	3.117E+03
Pu236	2.557E-04	2.198E-04	5.252E-04	1.213E-04	1.564E-05	4.235E-06	1.374E-04	1.499E-04	1.433E-04	3.427E+03	4.250E+03
Pu238	2.314E-04	1.989E-04	4.756E-04	1.099E-04	1.417E-05	3.835E-06	1.243E-04	1.356E-04	1.297E-04	3.785E+03	4.694E+03
Pu239	1.526E-04	1.313E-04	3.133E-04	7.240E-05	9.332E-06	2.522E-06	8.189E-05	8.941E-05	8.545E-05	5.745E+03	7.136E+03
Pu240	1.224E-03	1.052E-03	2.531E-03	5.857E-04	7.580E-05	2.051E-05	6.668E-04	7.252E-04	6.962E-04	7.111E+02	8.775E+02
Pu241	3.184E-09	2.739E-09	6.534E-09	1.511E-09	1.948E-10	5.259E-11	1.708E-09	1.866E-09	1.783E-09	2.755E+08	3.423E+08
Pu242	1.028E-01	8.838E-02	2.128E-01	4.925E-02	6.377E-03	1.726E-03	5.614E-02	6.104E-02	5.863E-02	8.458E+00	1.043E+01
Pu243	7.085E-07	1.340E-06	1.534E-06	2.954E-07	3.465E-08	9.614E-09	1.139E-05	1.851E-05	1.339E-05	4.861E+05	4.861E+05
Pu244	2.383E+01	2.049E+01	4.938E+01	1.143E+01	1.481E+00	4.008E-01	1.302E+01	1.415E+01	1.360E+01	3.646E-02	4.492E-02
Pu246	9.334E-07	2.112E-06	1.974E-06	3.722E-07	4.348E-08	1.183E-08	2.944E-05	5.220E-05	3.565E-05	1.724E+05	1.724E+05
Ra223	2.396E-04	2.232E-04	4.945E-04	1.126E-04	1.444E-05	3.911E-06	3.609E-04	5.138E-04	4.065E-04	3.640E+03	4.602E+03
Ra224	2.199E-04	1.893E-04	4.514E-04	1.042E-04	1.343E-05	3.635E-06	1.243E-04	1.397E-04	1.307E-04	3.988E+03	4.951E+03
Ra225	1.297E-09	2.640E-09	2.781E-09	5.309E-10	6.223E-11	1.717E-11	2.890E-08	4.954E-08	3.457E-08	1.817E+08	1.817E+08
Ra226	1.201E-04	1.033E-04	2.464E-04	5.699E-05	7.350E-06	1.983E-06	6.445E-05	7.037E-05	6.727E-05	7.305E+03	9.077E+03
Rb86	7.710E-03	9.928E-03	1.735E-02	3.677E-03	4.700E-04	1.242E-04	3.080E-02	4.140E-02	3.388E-02	1.038E+02	1.449E+02
Rb87	1.170E-10	2.575E-10	2.484E-10	4.704E-11	5.506E-12	1.507E-12	3.646E-09	6.591E-09	4.443E-09	1.366E+09	1.366E+09
Re188	2.218E-03	2.731E-03	5.020E-03	1.087E-03	1.435E-04	4.003E-05	8.052E-03	1.067E-02	8.808E-03	3.586E+02	4.497E+02

Table 7.5-5 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Rh102	6.966E-03	9.070E-03	1.567E-02	3.335E-03	4.300E-04	1.159E-04	3.070E-02	4.227E-02	3.406E-02	1.149E+02	1.554E+02
Rh106	1.115E-02	1.346E-02	2.518E-02	5.538E-03	7.351E-04	2.033E-04	3.861E-02	5.110E-02	4.222E-02	7.149E+01	8.853E+01
Rn219	3.775E-04	3.542E-04	7.803E-04	1.774E-04	2.271E-05	6.162E-06	5.723E-04	8.027E-04	6.426E-04	2.307E+03	2.921E+03
Rn220	3.122E-04	2.698E-04	6.413E-04	1.478E-04	1.906E-05	5.166E-06	1.838E-04	2.074E-04	1.935E-04	2.807E+03	3.484E+03
Rn222	1.973E-04	1.706E-04	4.052E-04	9.347E-05	1.204E-05	3.259E-06	1.164E-04	1.317E-04	1.226E-04	4.442E+03	5.523E+03
Ru103	6.557E-04	1.100E-03	1.451E-03	2.845E-04	3.424E-05	9.151E-06	6.627E-03	1.013E-02	7.648E-03	8.888E+02	8.888E+02
S35	3.574E-13	1.142E-12	6.970E-13	1.297E-13	1.540E-14	4.160E-15	4.830E-11	1.032E-10	6.259E-11	8.717E+10	8.717E+10
Sb124	3.480E-01	4.011E-01	7.883E-01	1.755E-01	2.347E-02	6.611E-03	9.994E-01	1.261E+00	1.073E+00	2.283E+00	2.723E+00
Sb125	1.473E-03	2.325E-03	3.298E-03	6.516E-04	8.223E-05	2.082E-05	1.183E-02	1.753E-02	1.349E-02	5.133E+02	5.133E+02
Sb126	2.860E-02	4.094E-02	6.424E-02	1.313E-02	1.679E-03	4.469E-04	1.670E-01	2.380E-01	1.879E-01	2.802E+01	3.782E+01
Sb126m	1.070E-02	1.569E-02	2.400E-02	4.883E-03	6.199E-04	1.591E-04	6.837E-02	9.881E-02	7.723E-02	7.501E+01	9.108E+01
Sc46	1.073E-01	1.405E-01	2.416E-01	5.090E-02	6.508E-03	1.716E-03	4.532E-01	6.145E-01	5.003E-01	7.451E+00	1.049E+01
Se75	5.961E-05	1.053E-04	1.307E-04	2.546E-05	2.974E-06	8.206E-07	7.465E-04	1.179E-03	8.714E-04	7.631E+03	7.631E+03
Se79	4.179E-13	1.335E-12	8.149E-13	1.516E-13	1.800E-14	4.863E-15	5.647E-11	1.207E-10	7.318E-11	7.456E+10	7.456E+10
Sm145	1.583E-08	2.750E-08	3.480E-08	6.789E-09	7.922E-10	2.189E-10	1.801E-07	2.788E-07	2.090E-07	3.228E+07	3.228E+07
Sm146	7.431E-07	6.379E-07	1.552E-06	3.595E-07	4.667E-08	1.264E-08	4.253E-07	4.596E-07	4.420E-07	1.160E+06	1.424E+06
Sm147	3.553E-07	3.051E-07	7.424E-07	1.719E-07	2.229E-08	6.052E-09	2.076E-07	2.241E-07	2.147E-07	2.425E+06	2.974E+06
Sm148	5.512E-08	4.834E-08	1.166E-07	2.702E-08	3.522E-09	9.624E-10	3.969E-08	4.448E-08	4.142E-08	1.544E+07	1.870E+07
Sn113	1.164E-07	2.389E-07	2.508E-07	4.801E-08	5.775E-09	1.529E-09	2.826E-06	4.921E-06	3.400E-06	1.829E+06	1.829E+06
Sn123	5.933E-04	7.691E-04	1.335E-03	2.823E-04	3.606E-05	9.537E-06	2.442E-03	3.302E-03	2.692E-03	1.349E+03	1.887E+03
Sn126	1.950E-09	3.954E-09	4.183E-09	7.990E-10	9.366E-11	2.585E-11	4.261E-08	7.281E-08	5.092E-08	1.236E+08	1.236E+08
Sr85	1.655E-03	2.688E-03	3.678E-03	7.229E-04	8.806E-05	2.378E-05	1.442E-02	2.160E-02	1.653E-02	4.166E+02	4.166E+02
Sr89	6.032E-05	8.577E-05	1.354E-04	2.779E-05	3.515E-06	9.466E-07	3.531E-04	5.056E-04	3.978E-04	1.330E+04	1.780E+04
Sr90	9.506E-08	1.770E-07	2.066E-07	3.992E-08	4.681E-09	1.294E-09	1.475E-06	2.401E-06	1.735E-06	3.749E+06	3.749E+06
Ta182	1.130E-01	1.423E-01	2.547E-01	5.423E-02	7.225E-03	1.950E-03	4.244E-01	5.648E-01	4.654E-01	7.068E+00	9.232E+00
Tb160	5.172E-02	6.737E-02	1.166E-01	2.457E-02	3.188E-03	8.627E-04	2.180E-01	2.954E-01	2.407E-01	1.544E+01	2.086E+01
Tc99	3.255E-10	6.860E-10	6.949E-10	1.322E-10	1.548E-11	4.256E-12	8.457E-09	1.487E-08	1.021E-08	6.052E+08	6.052E+08
Tc99m	4.048E-09	1.283E-08	7.910E-09	1.472E-09	1.748E-10	4.725E-11	5.382E-07	1.150E-06	6.972E-07	7.828E+06	7.828E+06
Te121	1.701E-03	2.763E-03	3.778E-03	7.425E-04	9.043E-05	2.443E-05	1.485E-02	2.224E-02	1.701E-02	4.047E+02	4.047E+02
Te121m	2.281E-03	2.940E-03	5.131E-03	1.087E-03	1.389E-04	3.674E-05	9.192E-03	1.239E-02	1.012E-02	3.508E+02	4.900E+02
Te123m	3.764E-09	1.201E-08	7.343E-09	1.366E-09	1.622E-10	4.382E-11	5.073E-07	1.084E-06	6.573E-07	8.301E+06	8.301E+06

Table 7.5-5 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Te125m	1.250E-11	3.991E-11	2.437E-11	4.534E-12	5.383E-13	1.454E-13	1.689E-09	3.610E-09	2.188E-09	2.493E+09	2.493E+09
Te127	5.126E-06	8.930E-06	1.126E-05	2.196E-06	2.566E-07	7.085E-08	5.933E-05	9.216E-05	6.889E-05	9.766E+04	9.766E+04
Te127m	4.877E-07	7.614E-07	1.094E-06	2.164E-07	2.753E-08	6.932E-09	3.728E-06	5.480E-06	4.236E-06	1.642E+06	1.642E+06
Te129	7.921E-04	1.052E-03	1.780E-03	3.742E-04	4.776E-05	1.268E-05	3.643E-03	5.039E-03	4.050E-03	1.011E+03	1.419E+03
Te129m	3.014E-04	4.411E-04	6.756E-04	1.372E-04	1.737E-05	4.561E-06	1.865E-03	2.677E-03	2.105E-03	2.664E+03	3.362E+03
Th227	2.025E-04	1.871E-04	4.175E-04	9.531E-05	1.223E-05	3.317E-06	3.084E-04	4.497E-04	3.496E-04	4.311E+03	5.427E+03
Th228	1.841E-04	1.583E-04	3.779E-04	8.728E-05	1.125E-05	3.043E-06	9.894E-05	1.082E-04	1.033E-04	4.764E+03	5.915E+03
Th229	1.280E-04	1.107E-04	2.628E-04	6.072E-05	7.826E-06	2.113E-06	7.816E-05	9.109E-05	8.299E-05	6.849E+03	8.520E+03
Th230	1.113E-04	9.574E-05	2.283E-04	5.281E-05	6.812E-06	1.837E-06	5.955E-05	6.495E-05	6.214E-05	7.885E+03	9.798E+03
Th231	5.276E-09	1.092E-08	1.129E-08	2.152E-09	2.521E-10	6.943E-11	1.268E-07	2.202E-07	1.524E-07	4.088E+07	4.088E+07
Th232	5.256E-05	4.527E-05	1.080E-04	2.507E-05	3.246E-06	8.719E-07	2.813E-05	3.073E-05	2.949E-05	1.667E+04	2.064E+04
Th234	1.140E-11	3.640E-11	2.222E-11	4.134E-12	4.909E-13	1.326E-13	1.540E-09	3.292E-09	1.996E-09	2.734E+09	2.734E+09
Tl206	9.883E-07	1.397E-06	2.237E-06	4.580E-07	5.866E-08	1.536E-08	5.278E-06	7.390E-06	5.909E-06	8.046E+05	1.172E+06
Tl207	8.189E-05	1.170E-04	1.847E-04	3.775E-05	4.804E-06	1.270E-06	4.672E-04	6.634E-04	5.254E-04	9.746E+03	1.357E+04
Tl208	2.269E+00	2.429E+00	5.159E+00	1.201E+00	1.655E-01	4.568E-02	5.022E+00	6.130E+00	5.350E+00	3.489E-01	3.940E-01
Tl209	4.919E-01	5.709E-01	1.117E+00	2.466E-01	3.281E-02	9.255E-03	1.432E+00	1.804E+00	1.535E+00	1.612E+00	1.945E+00
Tm168	2.221E-02	3.094E-02	5.013E-02	1.032E-02	1.330E-03	3.560E-04	1.156E-01	1.615E-01	1.292E-01	3.591E+01	5.056E+01
Tm170	2.477E-06	4.012E-06	5.499E-06	1.087E-06	1.335E-07	3.591E-08	2.289E-05	3.488E-05	2.636E-05	2.580E+05	2.580E+05
Tm171	3.418E-20	1.092E-19	6.665E-20	1.240E-20	1.472E-21	3.978E-22	4.619E-18	9.873E-18	5.985E-18	9.116E+17	9.116E+17
U232	1.715E-04	1.475E-04	3.521E-04	8.134E-05	1.048E-05	2.835E-06	9.189E-05	1.003E-04	9.587E-05	5.112E+03	6.349E+03
U233	1.230E-04	1.058E-04	2.524E-04	5.836E-05	7.526E-06	2.031E-06	6.602E-05	7.212E-05	6.891E-05	7.132E+03	8.863E+03
U234	1.193E-04	1.027E-04	2.448E-04	5.663E-05	7.303E-06	1.970E-06	6.387E-05	6.965E-05	6.663E-05	7.352E+03	9.136E+03
U235	7.889E-05	6.835E-05	1.619E-04	3.747E-05	4.838E-06	1.303E-06	5.194E-05	6.328E-05	5.585E-05	1.112E+04	1.382E+04
U236	1.068E-04	9.190E-05	2.194E-04	5.080E-05	6.561E-06	1.768E-06	5.733E-05	6.247E-05	5.984E-05	8.203E+03	1.018E+04
U237	1.970E-06	4.066E-06	4.217E-06	8.037E-07	9.415E-08	2.592E-08	4.554E-05	7.807E-05	5.449E-05	1.153E+05	1.153E+05
U238	9.412E-03	8.093E-03	1.951E-02	4.518E-03	5.854E-04	1.584E-04	5.145E-03	5.593E-03	5.374E-03	9.226E+01	1.136E+02
U239	1.987E-04	2.797E-04	4.480E-04	9.199E-05	1.162E-05	3.127E-06	1.078E-03	1.515E-03	1.207E-03	4.018E+03	5.755E+03
U240	3.649E-09	7.741E-09	7.786E-09	1.480E-09	1.733E-10	4.757E-11	9.502E-08	1.662E-07	1.145E-07	5.416E+07	5.416E+07
W181	5.092E-12	1.627E-11	9.931E-12	1.847E-12	2.193E-13	5.927E-14	6.882E-10	1.471E-09	8.918E-10	6.118E+09	6.118E+09
W185	1.017E-08	1.995E-08	2.193E-08	4.205E-09	4.929E-10	1.363E-10	1.937E-07	3.241E-07	2.298E-07	2.777E+07	2.777E+07
W188	2.629E-08	5.901E-08	5.567E-08	1.050E-08	1.227E-09	3.343E-10	8.060E-07	1.424E-06	9.747E-07	6.322E+06	6.322E+06

Table 7.5-5 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Xe127	1.638E-05	3.208E-05	3.532E-05	6.771E-06	7.966E-07	2.197E-07	3.079E-04	5.131E-04	3.648E-04	1.754E+04	1.754E+04
Xe131m	8.666E-11	2.768E-10	1.690E-10	3.144E-11	3.733E-12	1.009E-12	1.171E-08	2.503E-08	1.518E-08	3.595E+08	3.595E+08
Y88	7.425E-01	8.448E-01	1.687E+00	3.771E-01	5.119E-02	1.483E-02	2.043E+00	2.563E+00	2.192E+00	1.067E+00	1.214E+00
Y89m	3.455E-02	4.661E-02	7.782E-02	1.623E-02	2.008E-03	5.625E-04	1.645E-01	2.261E-01	1.826E-01	2.313E+01	3.200E+01
Y90	6.562E-04	8.461E-04	1.479E-03	3.150E-04	4.109E-05	1.122E-05	2.762E-03	3.760E-03	3.053E-03	1.217E+03	1.605E+03
Y90m	4.486E-04	7.780E-04	9.862E-04	1.925E-04	2.253E-05	6.201E-06	5.115E-03	7.935E-03	5.938E-03	1.134E+03	1.134E+03
Y91	4.541E-04	5.751E-04	1.024E-03	2.174E-04	2.951E-05	8.063E-06	1.784E-03	2.400E-03	1.964E-03	1.758E+03	2.232E+03
Zn65	4.384E-02	5.640E-02	9.863E-02	2.091E-02	2.673E-03	7.061E-04	1.744E-01	2.343E-01	1.918E-01	1.825E+01	2.549E+01
Zr88	7.473E-05	1.430E-04	1.615E-04	3.103E-05	3.642E-06	1.011E-06	1.249E-03	2.036E-03	1.468E-03	4.420E+03	4.420E+03
Zr90m	1.445E+00	1.575E+00	3.260E+00	7.510E-01	1.022E-01	2.901E-02	3.445E+00	4.211E+00	3.664E+00	5.522E-01	6.205E-01
Zr95	1.010E-02	1.475E-02	2.256E-02	4.551E-03	5.739E-04	1.637E-04	6.128E-02	8.717E-02	6.908E-02	7.977E+01	1.032E+02

Table 7.5-6 – [redacted]SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side(1)	Top	Bottom	Side	
Ac225	2.378E-04	2.064E-04	4.886E-04	6.116E-05	1.508E-04	1.751E-04	1.600E-04	1.472E+03
Ac227	1.847E-06	1.593E-06	3.792E-06	4.760E-07	1.036E-06	1.152E-06	1.086E-06	1.891E+05
Ac228	6.468E-02	7.920E-02	1.464E-01	1.716E-02	2.282E-01	2.996E-01	2.487E-01	5.246E+00
Ag108	1.908E-04	2.770E-04	4.284E-04	4.643E-05	1.193E-03	1.720E-03	1.347E-03	1.938E+03
Ag108m	1.290E-02	1.926E-02	2.885E-02	3.075E-03	8.525E-02	1.229E-01	9.645E-02	2.927E+01
Ag110	2.266E-03	2.828E-03	5.116E-03	5.976E-04	8.711E-03	1.171E-02	9.580E-03	1.506E+02
Ag110m	1.801E-01	2.224E-01	4.073E-01	4.771E-02	6.445E-01	8.497E-01	7.037E-01	1.886E+00
Am241	1.943E-04	1.670E-04	3.988E-04	5.003E-05	1.043E-04	1.139E-04	1.089E-04	1.799E+03
Am242	1.038E-07	1.879E-07	2.268E-07	2.288E-08	1.479E-06	2.401E-06	1.739E-06	3.749E+06
Am242m	1.687E-06	1.451E-06	3.479E-06	4.376E-07	9.193E-07	1.005E-06	9.604E-07	2.056E+05
Am243	1.679E-04	1.444E-04	3.446E-04	4.325E-05	9.025E-05	9.860E-05	9.418E-05	2.081E+03
Am245	1.426E-06	2.518E-06	3.132E-06	3.205E-07	1.985E-05	3.247E-05	2.339E-05	2.772E+05
Am246	6.554E-03	9.711E-03	1.471E-02	1.571E-03	4.173E-02	6.000E-02	4.714E-02	5.730E+01
At217	3.447E-04	2.967E-04	7.080E-04	8.881E-05	1.899E-04	2.088E-04	1.985E-04	1.013E+03
Au198	6.332E-04	1.029E-03	1.400E-03	1.461E-04	6.009E-03	9.164E-03	6.930E-03	6.160E+02
Ba133	6.891E-05	1.319E-04	1.489E-04	1.478E-05	1.156E-03	1.886E-03	1.359E-03	4.773E+03
Ba137m	3.173E-03	4.937E-03	7.128E-03	7.436E-04	2.395E-02	3.513E-02	2.719E-02	1.210E+02
Ba140	4.515E-04	7.370E-04	1.002E-03	1.040E-04	4.027E-03	6.053E-03	4.621E-03	8.651E+02
Be10	8.660E-08	1.613E-07	1.882E-07	1.885E-08	1.347E-06	2.194E-06	1.586E-06	4.101E+06
Bi207	1.010E-01	1.262E-01	2.278E-01	2.644E-02	3.729E-01	4.946E-01	4.079E-01	3.404E+00
Bi210	8.349E-06	1.284E-05	1.864E-05	1.975E-06	6.415E-05	9.538E-05	7.326E-05	4.557E+04
Bi211	3.474E-04	3.091E-04	7.145E-04	8.908E-05	3.485E-04	4.703E-04	3.857E-04	1.010E+03
Bi212	1.122E-02	1.331E-02	2.540E-02	3.031E-03	3.574E-02	4.607E-02	3.867E-02	2.970E+01
Bi213	5.505E-04	7.736E-04	1.232E-03	1.360E-04	3.229E-03	4.660E-03	3.647E-03	6.616E+02
Bi214	3.144E-01	3.607E-01	7.113E-01	8.661E-02	8.892E-01	1.123E+00	9.554E-01	1.039E+00
Bk247	1.167E-06	2.639E-06	2.469E-06	2.408E-07	3.662E-05	6.483E-05	4.432E-05	1.388E+05
Bk249	1.483E-05	1.275E-05	3.070E-05	3.868E-06	8.098E-06	8.803E-06	8.455E-06	2.327E+04
Bk250	5.241E-02	6.841E-02	1.180E-01	1.331E-02	2.210E-01	2.991E-01	2.438E-01	6.762E+00
C14	2.430E-13	7.762E-13	4.739E-13	4.564E-14	3.284E-11	7.020E-11	4.256E-11	1.282E+11
Ca45	5.167E-11	1.188E-10	1.089E-10	1.063E-11	1.939E-09	3.604E-09	2.386E-09	2.497E+09
Cd113	8.784E-10	1.809E-09	1.881E-09	1.855E-10	2.057E-08	3.555E-08	2.468E-08	2.532E+08
Cd113m	9.860E-08	1.822E-07	2.146E-07	2.154E-08	1.492E-06	2.422E-06	1.754E-06	3.716E+06
Cd115m	2.201E-03	2.819E-03	4.962E-03	5.641E-04	8.896E-03	1.198E-02	9.801E-03	1.596E+02
Ce141	3.665E-08	7.147E-08	7.912E-08	7.901E-09	8.417E-07	1.523E-06	1.026E-06	5.910E+06
Ce144	1.019E-09	2.665E-09	2.087E-09	2.035E-10	7.944E-08	1.648E-07	1.018E-07	5.463E+07
Cf249	4.438E-04	4.477E-04	9.214E-04	1.123E-04	1.255E-03	1.936E-03	1.449E-03	8.013E+02
Cf250	2.204E+01	1.895E+01	4.582E+01	5.793E+00	1.209E+01	1.311E+01	1.261E+01	1.554E-02
Cf251	2.362E-04	2.036E-04	4.849E-04	6.081E-05	1.393E-04	1.606E-04	1.475E-04	1.480E+03
Cf252	1.013E+03	8.710E+02	2.095E+03	2.638E+02	5.533E+02	6.014E+02	5.775E+02	3.411E-04
Cf253	8.151E-07	7.008E-07	1.673E-06	2.099E-07	4.431E-07	4.875E-07	4.633E-07	4.288E+05
Cf254	3.144E+04	2.704E+04	6.538E+04	8.264E+03	1.725E+04	1.871E+04	1.799E+04	1.089E-05
Cl36	8.964E-07	1.509E-06	1.981E-06	2.039E-07	9.308E-06	1.437E-05	1.077E-05	4.415E+05
Cm240	1.120E-03	9.629E-04	2.312E-03	2.908E-04	6.088E-04	6.622E-04	6.353E-04	3.095E+02
Cm242	1.669E-03	1.435E-03	3.449E-03	4.343E-04	9.088E-04	9.886E-04	9.488E-04	2.072E+02

Table 7.5-6 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Cm243	2.407E-04	2.085E-04	4.942E-04	6.193E-05	1.644E-04	2.037E-04	1.775E-04	1.453E+03
Cm244	3.217E-02	2.767E-02	6.658E-02	8.389E-03	1.757E-02	1.910E-02	1.834E-02	1.073E+01
Cm245	3.304E-04	2.841E-04	6.807E-04	8.558E-05	1.788E-04	1.951E-04	1.867E-04	1.052E+03
Cm246	7.232E+00	6.219E+00	1.497E+01	1.886E+00	3.949E+00	4.293E+00	4.123E+00	4.771E-02
Cm247	4.781E-04	7.123E-04	1.031E-03	1.111E-04	3.987E-03	6.141E-03	4.617E-03	8.098E+02
Cm248	2.249E+03	1.934E+03	4.656E+03	5.870E+02	1.228E+03	1.335E+03	1.282E+03	1.533E-04
Cm249	8.305E-05	1.306E-04	1.861E-04	1.939E-05	6.524E-04	9.633E-04	7.426E-04	4.641E+03
Cm250	3.936E+00	4.225E+00	8.924E+00	1.148E+00	9.081E+00	1.118E+01	9.693E+00	7.837E-02
Co57	7.707E-06	1.181E-05	1.725E-05	1.812E-06	5.526E-05	8.111E-05	6.282E-05	4.967E+04
Co58	2.286E-02	3.176E-02	5.173E-02	5.714E-03	1.176E-01	1.640E-01	1.314E-01	1.575E+01
Co60	2.340E-01	2.941E-01	5.275E-01	6.065E-02	8.738E-01	1.162E+00	9.578E-01	1.484E+00
Cr51	7.612E-06	1.456E-05	1.645E-05	1.633E-06	1.272E-04	2.074E-04	1.496E-04	4.339E+04
Cs134	2.400E-02	3.319E-02	5.390E-02	5.977E-03	1.254E-01	1.758E-01	1.403E-01	1.506E+01
Cs135	1.137E-12	3.568E-12	2.228E-12	2.148E-13	1.466E-10	3.125E-10	1.897E-10	2.880E+10
Cs137	5.827E-07	9.049E-07	1.299E-06	1.374E-07	4.723E-06	7.099E-06	5.412E-06	6.549E+05
Cu64	1.761E-03	2.396E-03	3.953E-03	4.465E-04	9.122E-03	1.291E-02	1.023E-02	2.016E+02
Dy159	7.798E-10	1.494E-09	1.685E-09	1.673E-10	1.313E-08	2.145E-08	1.545E-08	4.197E+08
Es252	2.826E-03	4.037E-03	6.333E-03	6.864E-04	1.607E-02	2.268E-02	1.805E-02	1.311E+02
Es253	3.180E-03	2.734E-03	6.603E-03	8.340E-04	1.742E-03	1.891E-03	1.817E-03	1.079E+02
Es254	1.294E-03	1.113E-03	2.682E-03	3.384E-04	7.085E-04	7.710E-04	7.395E-04	2.660E+02
Es254m	1.442E+01	1.240E+01	2.997E+01	3.789E+00	7.913E+00	8.586E+00	8.257E+00	2.375E-02
Eu149	2.371E-05	3.959E-05	5.245E-05	5.417E-06	2.374E-04	3.645E-04	2.741E-04	1.662E+04
Eu150	3.719E-02	4.728E-02	8.381E-02	9.663E-03	1.475E-01	1.988E-01	1.625E-01	9.314E+00
Eu152	8.955E-02	1.120E-01	2.019E-01	2.341E-02	3.262E-01	4.316E-01	3.569E-01	3.845E+00
Eu154	8.960E-02	1.126E-01	2.021E-01	2.328E-02	3.381E-01	4.502E-01	3.708E-01	3.866E+00
Eu155	9.493E-10	3.029E-09	1.852E-09	1.784E-10	1.279E-07	2.734E-07	1.657E-07	3.292E+07
Fe55	5.713E-18	1.825E-17	1.114E-17	1.073E-18	7.721E-16	1.650E-15	1.000E-15	5.454E+15
Fe59	1.129E-01	1.423E-01	2.545E-01	2.924E-02	4.244E-01	5.649E-01	4.654E-01	3.078E+00
Fr221	3.156E-04	2.728E-04	6.482E-04	8.124E-05	1.942E-04	2.263E-04	2.062E-04	1.108E+03
Fr223	1.355E-04	1.955E-04	3.044E-04	3.296E-05	7.961E-04	1.132E-03	8.964E-04	2.731E+03
Gd152	1.516E-07	1.308E-07	3.184E-07	4.028E-08	9.399E-08	1.024E-07	9.730E-08	2.235E+06
Gd153	9.438E-10	3.015E-09	1.841E-09	1.773E-10	1.276E-07	2.727E-07	1.653E-07	3.301E+07
Hf175	7.168E-05	1.359E-04	1.551E-04	1.543E-05	1.162E-03	1.888E-03	1.365E-03	4.767E+03
Hf181	4.065E-04	7.064E-04	8.934E-04	9.050E-05	4.652E-03	7.211E-03	5.398E-03	9.945E+02
Hg203	3.170E-06	7.165E-06	6.708E-06	6.542E-07	9.918E-05	1.754E-04	1.200E-04	5.130E+04
Ho166m	2.650E-02	3.705E-02	5.972E-02	6.567E-03	1.399E-01	1.960E-01	1.567E-01	1.370E+01
I129	1.222E-13	3.904E-13	2.384E-13	2.296E-14	1.652E-11	3.531E-11	2.141E-11	2.549E+11
I131	5.111E-04	8.008E-04	1.140E-03	1.196E-04	4.180E-03	6.259E-03	4.780E-03	7.527E+02
In113m	4.953E-05	9.475E-05	1.070E-04	1.063E-05	8.274E-04	1.349E-03	9.731E-04	6.670E+03
In114	4.483E-04	5.800E-04	1.010E-03	1.150E-04	1.901E-03	2.592E-03	2.104E-03	7.828E+02
In114m	3.879E-04	5.755E-04	8.659E-04	9.272E-05	2.502E-03	3.596E-03	2.830E-03	9.707E+02
In115	2.933E-08	5.607E-08	6.349E-08	6.323E-09	5.049E-07	8.332E-07	5.965E-07	1.080E+07
In115m	3.540E-05	6.768E-05	7.650E-05	7.597E-06	5.902E-04	9.622E-04	6.940E-04	9.353E+03
Ir194	3.609E-03	4.469E-03	8.148E-03	9.508E-04	1.314E-02	1.743E-02	1.438E-02	9.466E+01

Table 7.5-6 – [redacted]SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side(1)	Top	Bottom	Side	
K40	2.558E-02	3.120E-02	5.773E-02	6.795E-03	8.422E-02	1.093E-01	9.147E-02	1.325E+01
K42	9.540E-02	1.107E-01	2.165E-01	2.614E-02	2.778E-01	3.501E-01	2.978E-01	3.443E+00
Kr85	7.949E-06	1.297E-05	1.765E-05	1.833E-06	7.098E-05	1.068E-04	8.146E-05	4.911E+04
La140	5.754E-01	6.613E-01	1.306E+00	1.589E-01	1.628E+00	2.048E+00	1.746E+00	5.664E-01
Lu177	5.951E-07	1.281E-06	1.267E-06	1.243E-07	1.597E-05	2.785E-05	1.922E-05	3.232E+05
Lu177m	9.830E-05	1.719E-04	2.158E-04	2.185E-05	1.164E-03	1.817E-03	1.353E-03	4.119E+03
Mn54	1.976E-02	2.792E-02	4.473E-02	4.889E-03	1.055E-01	1.477E-01	1.181E-01	1.841E+01
Na22	1.497E-01	1.867E-01	3.378E-01	3.897E-02	5.538E-01	7.363E-01	6.073E-01	2.310E+00
Na24	2.509E+00	2.719E+00	5.699E+00	7.229E-01	5.788E+00	7.118E+00	6.180E+00	1.245E-01
Nb91	5.423E-06	8.808E-06	1.205E-05	1.253E-06	4.728E-05	7.081E-05	5.418E-05	7.185E+04
Nb94	2.996E-02	4.282E-02	6.752E-02	7.341E-03	1.674E-01	2.358E-01	1.879E-01	1.226E+01
Nb95	1.022E-02	1.492E-02	2.283E-02	2.456E-03	6.200E-02	8.819E-02	6.989E-02	3.664E+01
Nb95m	3.323E-06	5.828E-06	7.292E-06	7.557E-07	4.888E-05	8.150E-05	5.797E-05	1.104E+05
Nd144	2.975E-08	2.664E-08	6.342E-08	8.042E-09	2.564E-08	2.946E-08	2.692E-08	1.119E+07
Ni59	1.278E-09	2.076E-09	2.839E-09	2.952E-10	1.114E-08	1.669E-08	1.277E-08	3.049E+08
Np235	3.663E-09	3.194E-09	7.515E-09	9.427E-10	4.514E-09	7.608E-09	5.357E-09	9.547E+07
Np237	1.139E-04	9.800E-05	2.337E-04	2.936E-05	6.137E-05	6.723E-05	6.411E-05	3.065E+03
Np238	3.428E-02	4.477E-02	7.715E-02	8.701E-03	1.447E-01	1.960E-01	1.597E-01	1.034E+01
Np239	4.203E-06	8.425E-06	9.034E-06	8.934E-07	8.697E-05	1.470E-04	1.036E-04	6.122E+04
Np240	2.429E-02	3.315E-02	5.474E-02	6.043E-03	1.197E-01	1.659E-01	1.333E-01	1.489E+01
Np240m	1.391E-02	1.710E-02	3.144E-02	3.694E-03	4.970E-02	6.564E-02	5.428E-02	2.437E+01
Os185	5.463E-03	8.135E-03	1.231E-02	1.312E-03	3.561E-02	5.131E-02	4.021E-02	6.857E+01
Os194	5.161E-20	1.648E-19	1.007E-19	9.693E-21	6.975E-18	1.491E-17	9.038E-18	6.036E+17
P32	1.174E-04	1.625E-04	2.637E-04	2.916E-05	6.276E-04	8.871E-04	7.037E-04	3.086E+03
P33	3.478E-11	8.144E-11	7.306E-11	7.121E-12	1.424E-09	2.684E-09	1.761E-09	3.353E+09
Pa231	1.387E-04	1.259E-04	2.854E-04	3.548E-05	1.751E-04	2.469E-04	1.964E-04	2.537E+03
Pa233	4.822E-05	9.077E-05	1.045E-04	1.041E-05	7.609E-04	1.233E-03	8.933E-04	7.299E+03
Pa234	6.850E-02	8.628E-02	1.548E-01	1.791E-02	2.639E-01	3.525E-01	2.897E-01	5.026E+00
Pa234m	1.973E-03	2.458E-03	4.455E-03	5.176E-04	7.312E-03	9.723E-03	8.010E-03	1.739E+02
Pb209	1.684E-07	3.034E-07	3.682E-07	3.716E-08	2.311E-06	3.704E-06	2.706E-06	2.422E+06
Pb210	5.349E-13	4.610E-13	1.103E-12	1.393E-13	2.874E-13	3.152E-13	3.031E-13	6.459E+11
Pb211	1.018E-03	1.434E-03	2.297E-03	2.517E-04	5.493E-03	7.723E-03	6.157E-03	3.575E+02
Pb212	4.300E-06	8.804E-06	9.219E-06	9.093E-07	9.622E-05	1.642E-04	1.149E-04	5.482E+04
Pb214	2.686E-04	4.032E-04	6.010E-04	6.444E-05	1.921E-03	2.840E-03	2.189E-03	1.397E+03
Pm145	1.377E-17	1.498E-17	3.122E-17	3.968E-18	3.311E-17	4.102E-17	3.542E-17	2.268E+16
Pm146	6.176E-03	9.109E-03	1.379E-02	1.478E-03	3.924E-02	5.629E-02	4.435E-02	6.088E+01
Pm147	5.116E-12	1.327E-11	1.052E-11	1.022E-12	3.503E-10	7.109E-10	4.451E-10	1.266E+10
Pm148	5.945E-02	7.316E-02	1.342E-01	1.572E-02	2.039E-01	2.668E-01	2.222E-01	5.727E+00
Pm148m	3.267E-02	4.460E-02	7.340E-02	8.148E-03	1.637E-01	2.285E-01	1.827E-01	1.105E+01
Po209	9.293E-05	1.313E-04	2.104E-04	2.299E-05	4.965E-04	6.954E-04	5.559E-04	3.914E+03
Po210	1.728E-04	1.487E-04	3.547E-04	4.451E-05	9.351E-05	1.023E-04	9.763E-05	2.022E+03
Po211	4.628E-04	4.654E-04	9.750E-04	1.179E-04	8.496E-04	1.140E-03	9.391E-04	7.635E+02
Po212	3.440E-04	2.956E-04	7.065E-04	8.864E-05	1.850E-04	2.017E-04	1.930E-04	1.015E+03
Po213	3.445E-04	2.964E-04	7.076E-04	8.876E-05	1.880E-04	2.059E-04	1.963E-04	1.014E+03

Table 7.5-6 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Po214	3.451E-04	2.972E-04	7.088E-04	8.889E-05	1.914E-04	2.108E-04	2.002E-04	1.012E+03
Po215	3.448E-04	2.969E-04	7.083E-04	8.883E-05	1.913E-04	2.110E-04	2.002E-04	1.013E+03
Po216	3.444E-04	2.962E-04	7.073E-04	8.873E-05	1.870E-04	2.045E-04	1.952E-04	1.014E+03
Po218	2.659E-04	2.286E-04	5.458E-04	6.847E-05	1.436E-04	1.570E-04	1.499E-04	1.315E+03
Pr143	2.261E-06	3.684E-06	5.015E-06	5.208E-07	2.134E-05	3.260E-05	2.460E-05	1.728E+05
Pr144	1.297E-02	1.456E-02	2.927E-02	3.620E-03	3.446E-02	4.321E-02	3.698E-02	2.486E+01
Pr144m	3.021E-04	3.504E-04	6.859E-04	8.263E-05	8.850E-04	1.120E-03	9.509E-04	1.089E+03
Pu236	2.557E-04	2.198E-04	5.252E-04	6.591E-05	1.374E-04	1.499E-04	1.433E-04	1.365E+03
Pu238	2.314E-04	1.989E-04	4.756E-04	5.971E-05	1.243E-04	1.356E-04	1.297E-04	1.507E+03
Pu239	1.526E-04	1.313E-04	3.133E-04	3.933E-05	8.189E-05	8.941E-05	8.545E-05	2.288E+03
Pu240	1.224E-03	1.052E-03	2.531E-03	3.189E-04	6.668E-04	7.252E-04	6.962E-04	2.822E+02
Pu241	3.184E-09	2.739E-09	6.534E-09	8.208E-10	1.708E-09	1.866E-09	1.783E-09	1.096E+08
Pu242	1.028E-01	8.838E-02	2.128E-01	2.683E-02	5.614E-02	6.104E-02	5.863E-02	3.355E+00
Pu243	7.085E-07	1.340E-06	1.534E-06	1.528E-07	1.139E-05	1.851E-05	1.339E-05	4.861E+05
Pu244	2.383E+01	2.049E+01	4.938E+01	6.229E+00	1.302E+01	1.415E+01	1.360E+01	1.445E-02
Pu246	9.334E-07	2.112E-06	1.974E-06	1.926E-07	2.944E-05	5.220E-05	3.565E-05	1.724E+05
Ra223	2.396E-04	2.232E-04	4.945E-04	6.102E-05	3.609E-04	5.138E-04	4.065E-04	1.475E+03
Ra224	2.199E-04	1.893E-04	4.514E-04	5.660E-05	1.243E-04	1.397E-04	1.307E-04	1.590E+03
Ra225	1.297E-09	2.640E-09	2.781E-09	2.745E-10	2.890E-08	4.954E-08	3.457E-08	1.817E+08
Ra226	1.201E-04	1.033E-04	2.464E-04	3.097E-05	6.445E-05	7.037E-05	6.727E-05	2.906E+03
Rb86	7.710E-03	9.928E-03	1.735E-02	1.975E-03	3.080E-02	4.140E-02	3.388E-02	4.556E+01
Rb87	1.170E-10	2.575E-10	2.484E-10	2.433E-11	3.646E-09	6.591E-09	4.443E-09	1.366E+09
Re188	2.218E-03	2.731E-03	5.020E-03	5.873E-04	8.052E-03	1.067E-02	8.808E-03	1.532E+02
Rh102	6.966E-03	9.070E-03	1.567E-02	1.792E-03	3.070E-02	4.227E-02	3.406E-02	5.022E+01
Rh106	1.115E-02	1.346E-02	2.518E-02	3.000E-03	3.861E-02	5.110E-02	4.222E-02	3.000E+01
Rn219	3.775E-04	3.542E-04	7.803E-04	9.610E-05	5.723E-04	8.027E-04	6.426E-04	9.365E+02
Rn220	3.122E-04	2.698E-04	6.413E-04	8.037E-05	1.838E-04	2.074E-04	1.935E-04	1.120E+03
Rn222	1.973E-04	1.706E-04	4.052E-04	5.077E-05	1.164E-04	1.317E-04	1.226E-04	1.773E+03
Ru103	6.557E-04	1.100E-03	1.451E-03	1.485E-04	6.627E-03	1.013E-02	7.648E-03	6.061E+02
S35	3.574E-13	1.142E-12	6.970E-13	6.712E-14	4.830E-11	1.032E-10	6.259E-11	8.717E+10
Sb124	3.480E-01	4.011E-01	7.883E-01	9.570E-02	9.994E-01	1.261E+00	1.073E+00	9.404E-01
Sb125	1.473E-03	2.325E-03	3.298E-03	3.429E-04	1.183E-02	1.753E-02	1.349E-02	2.625E+02
Sb126	2.860E-02	4.094E-02	6.424E-02	6.979E-03	1.670E-01	2.380E-01	1.879E-01	1.290E+01
Sb126m	1.070E-02	1.569E-02	2.400E-02	2.582E-03	6.837E-02	9.881E-02	7.723E-02	3.486E+01
Sc46	1.073E-01	1.405E-01	2.416E-01	2.731E-02	4.532E-01	6.145E-01	5.003E-01	3.295E+00
Se75	5.961E-05	1.053E-04	1.307E-04	1.322E-05	7.465E-04	1.179E-03	8.714E-04	6.810E+03
Se79	4.179E-13	1.335E-12	8.149E-13	7.848E-14	5.647E-11	1.207E-10	7.318E-11	7.456E+10
Sm145	1.583E-08	2.750E-08	3.480E-08	3.524E-09	1.801E-07	2.788E-07	2.090E-07	2.554E+07
Sm146	7.431E-07	6.379E-07	1.552E-06	1.962E-07	4.253E-07	4.596E-07	4.420E-07	4.587E+05
Sm147	3.553E-07	3.051E-07	7.424E-07	9.383E-08	2.076E-07	2.241E-07	2.147E-07	9.592E+05
Sm148	5.512E-08	4.834E-08	1.166E-07	1.478E-08	3.969E-08	4.448E-08	4.142E-08	6.091E+06
Sn113	1.164E-07	2.389E-07	2.508E-07	2.499E-08	2.826E-06	4.921E-06	3.400E-06	1.829E+06
Sn123	5.933E-04	7.691E-04	1.335E-03	1.516E-04	2.442E-03	3.302E-03	2.692E-03	5.937E+02
Sn126	1.950E-09	3.954E-09	4.183E-09	4.131E-10	4.261E-08	7.281E-08	5.092E-08	1.236E+08

Table 7.5-6 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Sr85	1.655E-03	2.688E-03	3.678E-03	3.824E-04	1.442E-02	2.160E-02	1.653E-02	2.354E+02
Sr89	6.032E-05	8.577E-05	1.354E-04	1.479E-05	3.531E-04	5.056E-04	3.978E-04	6.083E+03
Sr90	9.506E-08	1.770E-07	2.066E-07	2.069E-08	1.475E-06	2.401E-06	1.735E-06	3.749E+06
Ta182	1.130E-01	1.423E-01	2.547E-01	2.926E-02	4.244E-01	5.648E-01	4.654E-01	3.076E+00
Tb160	5.172E-02	6.737E-02	1.166E-01	1.317E-02	2.180E-01	2.954E-01	2.407E-01	6.833E+00
Tc99	3.255E-10	6.860E-10	6.949E-10	6.836E-11	8.457E-09	1.487E-08	1.021E-08	6.052E+08
Tc99m	4.048E-09	1.283E-08	7.910E-09	7.622E-10	5.382E-07	1.150E-06	6.972E-07	7.828E+06
Te121	1.701E-03	2.763E-03	3.778E-03	3.928E-04	1.485E-02	2.224E-02	1.701E-02	2.291E+02
Te121m	2.281E-03	2.940E-03	5.131E-03	5.840E-04	9.192E-03	1.239E-02	1.012E-02	1.541E+02
Te123m	3.764E-09	1.201E-08	7.343E-09	7.072E-10	5.073E-07	1.084E-06	6.573E-07	8.301E+06
Te125m	1.250E-11	3.991E-11	2.437E-11	2.347E-12	1.689E-09	3.610E-09	2.188E-09	2.493E+09
Te127	5.126E-06	8.930E-06	1.126E-05	1.140E-06	5.933E-05	9.216E-05	6.889E-05	7.894E+04
Te127m	4.877E-07	7.614E-07	1.094E-06	1.142E-07	3.728E-06	5.480E-06	4.236E-06	7.884E+05
Te129	7.921E-04	1.052E-03	1.780E-03	2.005E-04	3.643E-03	5.039E-03	4.050E-03	4.488E+02
Te129m	3.014E-04	4.411E-04	6.756E-04	7.264E-05	1.865E-03	2.677E-03	2.105E-03	1.239E+03
Th227	2.025E-04	1.871E-04	4.175E-04	5.167E-05	3.084E-04	4.497E-04	3.496E-04	1.742E+03
Th228	1.841E-04	1.583E-04	3.779E-04	4.741E-05	9.894E-05	1.082E-04	1.033E-04	1.898E+03
Th229	1.280E-04	1.107E-04	2.628E-04	3.298E-05	7.816E-05	9.109E-05	8.299E-05	2.729E+03
Th230	1.113E-04	9.574E-05	2.283E-04	2.870E-05	5.955E-05	6.495E-05	6.214E-05	3.136E+03
Th231	5.276E-09	1.092E-08	1.129E-08	1.113E-09	1.268E-07	2.202E-07	1.524E-07	4.088E+07
Th232	5.256E-05	4.527E-05	1.080E-04	1.363E-05	2.813E-05	3.073E-05	2.949E-05	6.605E+03
Th234	1.140E-11	3.640E-11	2.222E-11	2.140E-12	1.540E-09	3.292E-09	1.996E-09	2.734E+09
Tl206	9.883E-07	1.397E-06	2.237E-06	2.445E-07	5.278E-06	7.390E-06	5.909E-06	3.681E+05
Tl207	8.189E-05	1.170E-04	1.847E-04	2.012E-05	4.672E-04	6.634E-04	5.254E-04	4.473E+03
Tl208	2.269E+00	2.429E+00	5.159E+00	6.590E-01	5.022E+00	6.130E+00	5.350E+00	1.366E-01
Tl209	4.919E-01	5.709E-01	1.117E+00	1.348E-01	1.432E+00	1.804E+00	1.535E+00	6.678E-01
Tm168	2.221E-02	3.094E-02	5.013E-02	5.517E-03	1.156E-01	1.615E-01	1.292E-01	1.631E+01
Tm170	2.477E-06	4.012E-06	5.499E-06	5.722E-07	2.289E-05	3.488E-05	2.636E-05	1.573E+05
Tm171	3.418E-20	1.092E-19	6.665E-20	6.418E-21	4.619E-18	9.873E-18	5.985E-18	9.116E+17
U232	1.715E-04	1.475E-04	3.521E-04	4.419E-05	9.189E-05	1.003E-04	9.587E-05	2.037E+03
U233	1.230E-04	1.058E-04	2.524E-04	3.171E-05	6.602E-05	7.212E-05	6.891E-05	2.838E+03
U234	1.193E-04	1.027E-04	2.448E-04	3.077E-05	6.387E-05	6.965E-05	6.663E-05	2.925E+03
U235	7.889E-05	6.835E-05	1.619E-04	2.036E-05	5.194E-05	6.328E-05	5.585E-05	4.420E+03
U236	1.068E-04	9.190E-05	2.194E-04	2.762E-05	5.733E-05	6.247E-05	5.984E-05	3.259E+03
U237	1.970E-06	4.066E-06	4.217E-06	4.155E-07	4.554E-05	7.807E-05	5.449E-05	1.153E+05
U238	9.412E-03	8.093E-03	1.951E-02	2.462E-03	5.145E-03	5.593E-03	5.374E-03	3.656E+01
U239	1.987E-04	2.797E-04	4.480E-04	4.891E-05	1.078E-03	1.515E-03	1.207E-03	1.840E+03
U240	3.649E-09	7.741E-09	7.786E-09	7.652E-10	9.502E-08	1.662E-07	1.145E-07	5.416E+07
W181	5.092E-12	1.627E-11	9.931E-12	9.564E-13	6.882E-10	1.471E-09	8.918E-10	6.118E+09
W185	1.017E-08	1.995E-08	2.193E-08	2.174E-09	1.937E-07	3.241E-07	2.298E-07	2.777E+07
W188	2.629E-08	5.901E-08	5.567E-08	5.434E-09	8.060E-07	1.424E-06	9.747E-07	6.322E+06
Xe127	1.638E-05	3.208E-05	3.532E-05	3.502E-06	3.079E-04	5.131E-04	3.648E-04	1.754E+04
Xe131m	8.666E-11	2.768E-10	1.690E-10	1.627E-11	1.171E-08	2.503E-08	1.518E-08	3.595E+08
Y88	7.425E-01	8.448E-01	1.687E+00	2.040E-01	2.043E+00	2.563E+00	2.192E+00	4.412E-01

Table 7.5-6 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Y89m	3.455E-02	4.661E-02	7.782E-02	8.581E-03	1.645E-01	2.261E-01	1.826E-01	1.049E+01
Y90	6.562E-04	8.461E-04	1.479E-03	1.694E-04	2.762E-03	3.760E-03	3.053E-03	5.313E+02
Y90m	4.486E-04	7.780E-04	9.862E-04	9.997E-05	5.115E-03	7.935E-03	5.938E-03	9.003E+02
Y91	4.541E-04	5.751E-04	1.024E-03	1.174E-04	1.784E-03	2.400E-03	1.964E-03	7.667E+02
Zn65	4.384E-02	5.640E-02	9.863E-02	1.123E-02	1.744E-01	2.343E-01	1.918E-01	8.011E+00
Zr88	7.473E-05	1.430E-04	1.615E-04	1.603E-05	1.249E-03	2.036E-03	1.468E-03	4.420E+03
Zr90m	1.445E+00	1.575E+00	3.260E+00	4.091E-01	3.445E+00	4.211E+00	3.664E+00	2.200E-01
Zr95	1.010E-02	1.475E-02	2.256E-02	2.428E-03	6.128E-02	8.717E-02	6.908E-02	3.707E+01

Notes:

[2] The dose rate at 1-meter from the side of the package bounds the dose rate at 1-meter from the top and bottom of the package based on inspection of the package surface dose rates. Therefore, 1-meter dose rates on the ends of the package are not reported.

Table 7.5-7 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Ac225	1.989E-04	2.165E-04	4.142E-04	9.654E-05	1.285E-05	3.457E-06	9.073E-05	1.011E-04	1.010E-04	4.346E+03	5.207E+03
Ac227	1.552E-06	1.687E-06	3.240E-06	7.553E-07	1.009E-07	2.700E-08	7.077E-07	7.878E-07	7.868E-07	5.555E+05	6.667E+05
Ac228	3.550E-02	4.703E-02	4.063E-02	8.653E-03	1.109E-03	3.036E-04	1.706E-02	2.237E-02	1.986E-02	3.827E+01	5.929E+01
Ag108	9.085E-05	1.301E-04	7.868E-05	1.576E-05	1.955E-06	5.259E-07	3.915E-05	5.544E-05	4.798E-05	1.383E+04	3.422E+04
Ag108m	5.967E-03	8.690E-03	4.696E-03	9.140E-04	1.111E-04	2.978E-05	2.476E-03	3.604E-03	3.073E-03	2.071E+02	6.045E+02
Ag110	1.231E-03	1.642E-03	1.399E-03	2.991E-04	3.862E-05	1.057E-05	5.924E-04	7.797E-04	6.884E-04	1.097E+03	1.703E+03
Ag110m	9.865E-02	1.311E-01	1.120E-01	2.383E-02	3.073E-03	8.381E-04	4.699E-02	6.225E-02	5.496E-02	1.373E+01	2.148E+01
Am241	1.634E-04	1.775E-04	3.415E-04	7.962E-05	1.061E-05	2.850E-06	7.459E-05	8.295E-05	8.293E-05	5.270E+03	6.317E+03
Am242	4.057E-08	6.442E-08	2.272E-08	4.252E-09	5.033E-10	1.360E-10	1.559E-08	2.498E-08	2.062E-08	2.794E+07	1.323E+08
Am242m	1.418E-06	1.545E-06	2.992E-06	6.979E-07	9.285E-08	2.493E-08	6.560E-07	7.302E-07	7.276E-07	6.016E+05	7.220E+05
Am243	1.412E-04	1.534E-04	2.951E-04	6.880E-05	9.178E-06	2.461E-06	6.444E-05	7.168E-05	7.164E-05	6.100E+03	7.314E+03
Am245	5.773E-07	9.003E-07	3.600E-07	6.848E-08	8.199E-09	2.208E-09	2.268E-07	3.553E-07	2.952E-07	1.999E+06	8.154E+06
Am246	3.057E-03	4.426E-03	2.454E-03	4.791E-04	5.812E-05	1.570E-05	1.269E-03	1.850E-03	1.585E-03	4.067E+02	1.147E+03
At217	2.896E-04	3.147E-04	6.052E-04	1.411E-04	1.875E-05	5.057E-06	1.323E-04	1.471E-04	1.472E-04	2.974E+03	3.559E+03
Au198	2.735E-04	4.117E-04	1.955E-04	3.805E-05	4.644E-06	1.262E-06	1.117E-04	1.666E-04	1.417E-04	4.372E+03	1.426E+04
Ba133	2.533E-05	4.149E-05	1.221E-05	2.248E-06	2.612E-07	6.944E-08	9.496E-06	1.578E-05	1.285E-05	4.338E+04	2.169E+05
Ba137m	1.411E-03	2.101E-03	1.028E-03	1.987E-04	2.398E-05	6.345E-06	5.789E-04	8.486E-04	7.271E-04	8.567E+02	2.837E+03
Ba140	1.931E-04	2.934E-04	1.292E-04	2.459E-05	2.948E-06	8.016E-07	7.619E-05	1.181E-04	9.875E-05	6.135E+03	2.246E+04
Be10	3.288E-08	5.299E-08	1.722E-08	3.200E-09	3.766E-10	1.015E-10	1.250E-08	2.034E-08	1.668E-08	3.397E+07	1.699E+08
Bi207	5.428E-02	7.293E-02	5.982E-02	1.256E-02	1.602E-03	4.366E-04	2.574E-02	3.377E-02	3.016E-02	2.468E+01	4.123E+01
Bi210	3.783E-06	5.559E-06	2.913E-06	5.682E-07	6.911E-08	1.865E-08	1.560E-06	2.299E-06	1.957E-06	3.238E+05	9.653E+05
Bi211	2.873E-04	3.142E-04	5.951E-04	1.386E-04	1.842E-05	4.968E-06	1.310E-04	1.463E-04	1.461E-04	3.025E+03	3.623E+03
Bi212	6.342E-03	8.279E-03	7.692E-03	1.661E-03	2.142E-04	5.895E-05	3.130E-03	4.020E-03	3.601E-03	2.174E+02	3.053E+02
Bi213	2.710E-04	3.810E-04	2.555E-04	5.196E-05	6.519E-06	1.765E-06	1.197E-04	1.652E-04	1.449E-04	4.724E+03	1.020E+04
Bi214	1.822E-01	2.350E-01	2.325E-01	5.109E-02	6.709E-03	1.839E-03	9.283E-02	1.183E-01	1.051E-01	7.658E+00	9.789E+00
Bk247	3.711E-07	6.614E-07	1.304E-07	2.353E-08	2.745E-09	7.236E-10	1.343E-07	2.422E-07	1.882E-07	2.721E+06	1.361E+07
Bk249	1.247E-05	1.360E-05	2.650E-05	6.183E-06	8.207E-07	2.207E-07	5.826E-06	6.489E-06	6.451E-06	6.792E+04	8.157E+04
Bk250	2.699E-02	3.707E-02	2.711E-02	5.538E-03	6.960E-04	1.877E-04	1.222E-02	1.652E-02	1.460E-02	4.856E+01	9.589E+01
C14	5.527E-14	1.174E-13	9.112E-15	1.634E-15	1.862E-16	5.376E-17	1.924E-14	4.093E-14	2.837E-14	1.533E+13	7.667E+13
Ca45	1.630E-11	2.912E-11	5.768E-12	1.043E-12	1.216E-13	3.216E-14	5.907E-12	1.067E-11	8.272E-12	6.181E+10	3.090E+11
Cd113	3.050E-10	5.160E-10	1.323E-10	2.422E-11	2.818E-12	7.473E-13	1.129E-10	1.934E-10	1.547E-10	3.488E+09	1.744E+10
Cd113m	3.774E-08	6.057E-08	2.016E-08	3.752E-09	4.425E-10	1.194E-10	1.439E-08	2.332E-08	1.916E-08	2.972E+07	1.486E+08

Table 7.5-7 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Cd115m	1.152E-03	1.562E-03	1.190E-03	2.461E-04	3.099E-05	8.399E-06	5.316E-04	7.171E-04	6.257E-04	1.152E+03	2.143E+03
Ce141	1.353E-08	2.210E-08	6.863E-09	1.274E-09	1.498E-10	4.037E-11	5.122E-09	8.441E-09	6.869E-09	8.143E+07	4.072E+08
Ce144	2.938E-10	5.464E-10	9.662E-11	1.761E-11	2.041E-12	5.503E-13	1.062E-10	1.984E-10	1.498E-10	3.294E+09	1.647E+10
Cf249	3.434E-04	3.866E-04	6.872E-04	1.598E-04	2.120E-05	5.698E-06	1.568E-04	1.793E-04	1.761E-04	2.619E+03	3.159E+03
Cf250	1.854E+01	2.027E+01	3.980E+01	9.298E+00	1.232E+00	3.308E-01	8.769E+00	9.776E+00	9.682E+00	4.522E-02	5.442E-02
Cf251	1.984E-04	2.156E-04	4.146E-04	9.665E-05	1.287E-05	3.461E-06	9.058E-05	1.007E-04	1.008E-04	4.342E+03	5.201E+03
Cf252	8.514E+02	9.285E+02	1.807E+03	4.214E+02	5.591E+01	1.506E+01	3.972E+02	4.422E+02	4.400E+02	9.962E-04	1.195E-03
Cf253	6.853E-07	7.444E-07	1.433E-06	3.340E-07	4.446E-08	1.197E-08	3.129E-07	3.479E-07	3.481E-07	1.256E+06	1.504E+06
Cf254	2.645E+04	2.892E+04	5.678E+04	1.326E+04	1.758E+03	4.719E+02	1.251E+04	1.395E+04	1.381E+04	3.170E-05	3.814E-05
Cl36	3.738E-07	5.748E-07	2.391E-07	4.533E-08	5.417E-09	1.469E-09	1.466E-07	2.289E-07	1.909E-07	3.132E+06	1.225E+07
Cm240	9.415E-04	1.026E-03	1.990E-03	4.640E-04	6.158E-05	1.660E-05	4.365E-04	4.858E-04	4.842E-04	9.047E+02	1.085E+03
Cm242	1.403E-03	1.530E-03	2.974E-03	6.937E-04	9.212E-05	2.477E-05	6.530E-04	7.271E-04	7.237E-04	6.053E+02	7.266E+02
Cm243	2.018E-04	2.195E-04	4.213E-04	9.823E-05	1.308E-05	3.517E-06	9.213E-05	1.025E-04	1.025E-04	4.272E+03	5.117E+03
Cm244	2.705E-02	2.951E-02	5.747E-02	1.341E-02	1.780E-03	4.786E-04	1.263E-02	1.407E-02	1.399E-02	3.132E+01	3.761E+01
Cm245	2.778E-04	3.024E-04	5.852E-04	1.365E-04	1.816E-05	4.878E-06	1.282E-04	1.426E-04	1.422E-04	3.076E+03	3.690E+03
Cm246	6.081E+00	6.634E+00	1.293E+01	3.016E+00	4.003E-01	1.076E-01	2.842E+00	3.165E+00	3.146E+00	1.393E-01	1.673E-01
Cm247	2.517E-04	3.394E-04	3.178E-04	7.039E-05	9.182E-06	2.467E-06	1.054E-04	1.417E-04	1.276E-04	5.304E+03	7.296E+03
Cm248	1.891E+03	2.063E+03	4.023E+03	9.388E+02	1.247E+02	3.348E+01	8.847E+02	9.855E+02	9.793E+02	4.474E-04	5.377E-04
Cm249	3.662E-05	5.477E-05	2.624E-05	5.055E-06	6.094E-07	1.621E-07	1.490E-05	2.211E-05	1.884E-05	3.287E+04	1.111E+05
Cm250	2.428E+00	3.030E+00	3.504E+00	8.079E-01	1.093E-01	3.018E-02	1.327E+00	1.647E+00	1.466E+00	5.137E-01	5.964E-01
Co57	3.479E-06	5.122E-06	2.618E-06	5.056E-07	6.060E-08	1.630E-08	1.413E-06	2.099E-06	1.803E-06	3.514E+05	1.104E+06
Co58	1.136E-02	1.590E-02	1.045E-02	2.106E-03	2.614E-04	7.154E-05	4.951E-03	6.971E-03	6.001E-03	1.132E+02	2.516E+02
Co60	1.244E-01	1.677E-01	1.327E-01	2.757E-02	3.492E-03	9.480E-04	5.850E-02	7.754E-02	6.831E-02	1.073E+01	1.899E+01
Cr51	2.800E-06	4.585E-06	1.351E-06	2.488E-07	2.891E-08	7.684E-09	1.050E-06	1.744E-06	1.421E-06	3.926E+05	1.963E+06
Cs134	1.195E-02	1.672E-02	1.122E-02	2.283E-03	2.879E-04	7.755E-05	5.252E-03	7.347E-03	6.359E-03	1.076E+02	2.321E+02
Cs135	2.647E-13	5.549E-13	4.769E-14	8.559E-15	9.791E-16	2.787E-16	9.244E-14	1.941E-13	1.358E-13	3.244E+12	1.622E+13
Cs137	2.623E-07	3.867E-07	2.002E-07	3.903E-08	4.747E-09	1.281E-09	1.080E-07	1.596E-07	1.356E-07	4.655E+06	1.405E+07
Cu64	8.985E-04	1.241E-03	9.042E-04	1.882E-04	2.423E-05	6.546E-06	4.036E-04	5.630E-04	4.871E-04	1.450E+03	2.750E+03
Dy159	2.865E-10	4.695E-10	1.379E-10	2.540E-11	2.951E-12	7.845E-13	1.074E-10	1.785E-10	1.454E-10	3.834E+09	1.917E+10
Es252	1.356E-03	1.932E-03	1.152E-03	2.273E-04	2.783E-05	7.489E-06	5.729E-04	8.220E-04	7.037E-04	9.315E+02	2.403E+03
Es253	2.675E-03	2.923E-03	5.726E-03	1.337E-03	1.773E-04	4.762E-05	1.261E-03	1.405E-03	1.393E-03	3.143E+02	3.780E+02
Es254	1.088E-03	1.188E-03	2.321E-03	5.419E-04	7.188E-05	1.931E-05	5.102E-04	5.684E-04	5.645E-04	7.755E+02	9.319E+02

Table 7.5-7 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Es254m	1.212E+01	1.326E+01	2.603E+01	6.081E+00	8.060E-01	2.163E-01	5.736E+00	6.395E+00	6.333E+00	6.915E-02	8.321E-02
Eu149	9.959E-06	1.526E-05	6.461E-06	1.227E-06	1.467E-07	3.980E-08	3.906E-06	6.107E-06	5.089E-06	1.179E+05	4.522E+05
Eu150	1.981E-02	2.672E-02	2.135E-02	4.472E-03	5.727E-04	1.554E-04	9.248E-03	1.238E-02	1.090E-02	6.735E+01	1.158E+02
Eu152	4.828E-02	6.479E-02	5.289E-02	1.110E-02	1.432E-03	3.867E-04	2.251E-02	3.021E-02	2.658E-02	2.778E+01	4.655E+01
Eu154	4.778E-02	6.427E-02	5.133E-02	1.072E-02	1.359E-03	3.698E-04	2.251E-02	2.989E-02	2.627E-02	2.801E+01	4.867E+01
Eu155	2.162E-10	4.589E-10	3.588E-11	6.433E-12	7.333E-13	2.115E-13	7.528E-11	1.600E-10	1.110E-10	3.923E+09	1.961E+10
Fe55	1.299E-18	2.759E-18	2.142E-19	3.840E-20	4.376E-21	1.264E-21	4.522E-19	9.621E-19	6.670E-19	6.523E+17	3.262E+18
Fe59	5.991E-02	8.089E-02	6.370E-02	1.322E-02	1.675E-03	4.544E-04	2.812E-02	3.728E-02	3.288E-02	2.225E+01	3.961E+01
Fr221	2.646E-04	2.878E-04	5.524E-04	1.288E-04	1.712E-05	4.615E-06	1.208E-04	1.344E-04	1.345E-04	3.258E+03	3.900E+03
Fr223	6.480E-05	9.258E-05	5.461E-05	1.075E-05	1.317E-06	3.566E-07	2.733E-05	3.935E-05	3.361E-05	1.944E+04	5.048E+04
Gd152	1.267E-07	1.387E-07	2.748E-07	6.395E-08	8.398E-09	2.279E-09	6.188E-08	6.882E-08	6.776E-08	6.550E+06	7.899E+06
Gd153	2.146E-10	4.559E-10	3.539E-11	6.345E-12	7.230E-13	2.088E-13	7.471E-11	1.590E-10	1.102E-10	3.948E+09	1.974E+10
Hf175	2.661E-05	4.336E-05	1.312E-05	2.421E-06	2.821E-07	7.526E-08	1.001E-05	1.653E-05	1.350E-05	4.151E+04	2.076E+05
Hf181	1.638E-04	2.560E-04	9.601E-05	1.800E-05	2.141E-06	5.844E-07	6.359E-05	9.968E-05	8.305E-05	7.031E+03	3.080E+04
Hg203	1.008E-06	1.797E-06	3.543E-07	6.394E-08	7.461E-09	1.967E-09	3.648E-07	6.580E-07	5.113E-07	1.002E+06	5.009E+06
Ho166m	1.306E-02	1.836E-02	1.179E-02	2.364E-03	2.935E-04	7.966E-05	5.648E-03	7.992E-03	6.867E-03	9.804E+01	2.260E+02
I129	2.780E-14	5.905E-14	4.583E-15	8.218E-16	9.364E-17	2.704E-17	9.676E-15	2.059E-14	1.427E-14	3.049E+13	1.524E+14
I131	2.271E-04	3.376E-04	1.668E-04	3.227E-05	3.901E-06	1.040E-06	9.292E-05	1.374E-04	1.168E-04	5.331E+03	1.731E+04
In113m	1.822E-05	2.983E-05	8.789E-06	1.618E-06	1.881E-07	4.999E-08	6.830E-06	1.135E-05	9.245E-06	6.034E+04	3.017E+05
In114	2.341E-04	3.184E-04	2.421E-04	5.018E-05	6.342E-06	1.722E-06	1.083E-04	1.458E-04	1.275E-04	5.653E+03	1.045E+04
In114m	1.805E-04	2.620E-04	1.435E-04	2.795E-05	3.399E-06	9.151E-07	7.483E-05	1.093E-04	9.291E-05	6.870E+03	1.967E+04
In115	1.087E-08	1.774E-08	5.397E-09	9.978E-10	1.169E-10	3.134E-11	4.099E-09	6.760E-09	5.513E-09	1.015E+08	5.073E+08
In115m	1.303E-05	2.133E-05	6.294E-06	1.159E-06	1.347E-07	3.583E-08	4.886E-06	8.112E-06	6.611E-06	8.440E+04	4.220E+05
Ir194	1.963E-03	2.617E-03	2.211E-03	4.686E-04	6.024E-05	1.641E-05	9.363E-04	1.234E-03	1.094E-03	6.877E+02	1.097E+03
K40	1.415E-02	1.876E-02	1.620E-02	3.443E-03	4.499E-04	1.214E-04	6.678E-03	8.959E-03	7.855E-03	9.596E+01	1.483E+02
K42	5.473E-02	7.092E-02	6.786E-02	1.474E-02	1.907E-03	5.259E-04	2.747E-02	3.500E-02	3.141E-02	2.538E+01	3.423E+01
Kr85	3.403E-06	5.167E-06	2.280E-06	4.340E-07	5.203E-08	1.414E-08	1.342E-06	2.081E-06	1.740E-06	3.483E+05	1.273E+06
La140	3.336E-01	4.300E-01	4.234E-01	9.284E-02	1.208E-02	3.356E-03	1.696E-01	2.151E-01	1.929E-01	4.186E+00	5.363E+00
Lu177	1.985E-07	3.439E-07	7.875E-08	1.434E-08	1.670E-09	4.421E-10	7.273E-08	1.275E-07	1.007E-07	5.234E+06	2.617E+07
Lu177m	3.943E-05	6.175E-05	2.300E-05	4.314E-06	5.130E-07	1.398E-07	1.529E-05	2.405E-05	2.001E-05	2.915E+04	1.288E+05
Mn54	9.664E-03	1.364E-02	8.482E-03	1.682E-03	2.069E-04	5.653E-05	4.124E-03	5.892E-03	5.042E-03	1.319E+02	3.184E+02
Na22	8.013E-02	1.074E-01	8.644E-02	1.807E-02	2.289E-03	6.231E-04	3.804E-02	5.042E-02	4.408E-02	1.676E+01	2.889E+01

Table 7.5-7 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Na24	1.542E+00	1.930E+00	2.191E+00	5.006E-01	6.694E-02	1.912E-02	8.340E-01	1.037E+00	9.253E-01	8.217E-01	9.413E-01
Nb91	2.330E-06	3.532E-06	1.571E-06	2.993E-07	3.589E-08	9.758E-09	9.199E-07	1.425E-06	1.192E-06	5.097E+05	1.845E+06
Nb94	1.447E-02	2.058E-02	1.239E-02	2.446E-03	3.000E-04	8.156E-05	6.132E-03	8.799E-03	7.519E-03	8.748E+01	2.207E+02
Nb95	4.817E-03	6.944E-03	3.919E-03	7.653E-04	9.323E-05	2.507E-05	2.011E-03	2.912E-03	2.482E-03	2.592E+02	7.179E+02
Nb95m	1.372E-06	2.117E-06	9.138E-07	1.756E-07	2.121E-08	5.709E-09	5.463E-07	8.480E-07	7.028E-07	8.503E+05	3.153E+06
Nd144	2.392E-08	2.672E-08	5.027E-08	1.170E-08	1.538E-09	4.186E-10	1.179E-08	1.334E-08	1.296E-08	3.581E+07	4.300E+07
Ni59	5.490E-10	8.323E-10	3.703E-10	7.053E-11	8.458E-12	2.300E-12	2.168E-10	3.358E-10	2.808E-10	2.163E+09	7.827E+09
Np235	3.069E-09	3.339E-09	6.406E-09	1.493E-09	1.995E-10	5.339E-11	1.400E-09	1.559E-09	1.556E-09	2.810E+08	3.371E+08
Np237	9.582E-05	1.041E-04	2.001E-04	4.666E-05	6.239E-06	1.667E-06	4.369E-05	4.862E-05	4.856E-05	8.994E+03	1.080E+04
Np238	1.764E-02	2.424E-02	1.770E-02	3.613E-03	4.539E-04	1.224E-04	7.982E-03	1.079E-02	9.541E-03	7.427E+01	1.471E+02
Np239	1.493E-06	2.494E-06	6.782E-07	1.246E-07	1.451E-08	3.857E-09	5.557E-07	9.400E-07	7.573E-07	7.218E+05	3.609E+06
Np240	1.210E-02	1.688E-02	1.125E-02	2.264E-03	2.807E-04	7.571E-05	5.279E-03	7.380E-03	6.407E-03	1.067E+02	2.378E+02
Np240m	7.644E-03	1.014E-02	8.764E-03	1.869E-03	2.412E-04	6.585E-05	3.663E-03	4.833E-03	4.275E-03	1.776E+02	2.733E+02
Os185	2.541E-03	3.689E-03	2.034E-03	3.984E-04	4.857E-05	1.307E-05	1.062E-03	1.538E-03	1.317E-03	4.880E+02	1.377E+03
Os194	1.174E-20	2.493E-20	1.935E-21	3.470E-22	3.954E-23	1.142E-23	4.085E-21	8.692E-21	6.026E-21	7.220E+19	3.610E+20
P32	5.812E-05	8.143E-05	5.420E-05	1.097E-05	1.370E-06	3.702E-07	2.560E-05	3.563E-05	3.097E-05	2.210E+04	4.862E+04
P33	1.080E-11	1.946E-11	3.693E-12	6.668E-13	7.773E-14	2.056E-14	3.901E-12	7.104E-12	5.480E-12	9.250E+10	4.625E+11
Pa231	1.136E-04	1.248E-04	2.336E-04	5.441E-05	7.265E-06	1.944E-06	5.165E-05	5.795E-05	5.762E-05	7.704E+03	9.258E+03
Pa233	1.804E-05	2.928E-05	9.052E-06	1.673E-06	1.955E-07	5.230E-08	6.807E-06	1.118E-05	9.150E-06	6.148E+04	3.074E+05
Pa234	3.683E-02	4.935E-02	4.043E-02	8.524E-03	1.090E-03	2.974E-04	1.730E-02	2.309E-02	2.034E-02	3.647E+01	6.052E+01
Pa234m	1.067E-03	1.427E-03	1.190E-03	2.511E-04	3.212E-05	8.772E-06	5.078E-04	6.675E-04	5.940E-04	1.261E+03	2.052E+03
Pb209	6.601E-08	1.047E-07	3.714E-08	6.951E-09	8.230E-10	2.225E-10	2.538E-08	4.062E-08	3.355E-08	1.720E+07	8.090E+07
Pb210	4.505E-13	4.919E-13	9.513E-13	2.222E-13	2.996E-14	7.853E-15	2.084E-13	2.335E-13	2.313E-13	1.892E+12	2.292E+12
Pb211	4.984E-04	7.034E-04	4.433E-04	8.834E-05	1.091E-05	2.969E-06	2.146E-04	3.039E-04	2.616E-04	2.559E+03	6.063E+03
Pb212	1.500E-06	2.532E-06	6.556E-07	1.201E-07	1.398E-08	3.709E-09	5.556E-07	9.497E-07	7.608E-07	7.109E+05	3.555E+06
Pb214	1.248E-04	1.810E-04	1.005E-04	1.970E-05	2.405E-06	6.520E-07	5.203E-05	7.600E-05	6.457E-05	9.946E+03	2.761E+04
Pm145	8.396E-18	1.055E-17	1.186E-17	2.709E-18	3.646E-19	1.007E-19	4.529E-18	5.648E-18	5.026E-18	1.518E+17	1.788E+17
Pm146	2.888E-03	4.179E-03	2.317E-03	4.519E-04	5.501E-05	1.480E-05	1.202E-03	1.746E-03	1.487E-03	4.307E+02	1.216E+03
Pm147	1.461E-12	2.747E-12	4.358E-13	7.857E-14	9.134E-15	2.443E-15	5.230E-13	9.902E-13	7.436E-13	6.554E+11	3.277E+12
Pm148	3.265E-02	4.341E-02	3.692E-02	7.828E-03	1.020E-03	2.752E-04	1.534E-02	2.062E-02	1.807E-02	4.146E+01	6.540E+01
Pm148m	1.629E-02	2.277E-02	1.542E-02	3.120E-03	3.899E-04	1.050E-04	7.222E-03	9.945E-03	8.721E-03	7.905E+01	1.714E+02
Po209	4.545E-05	6.417E-05	3.989E-05	7.911E-06	9.731E-07	2.659E-07	1.940E-05	2.771E-05	2.371E-05	2.805E+04	6.770E+04

Table 7.5-7 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Po210	1.453E-04	1.578E-04	3.036E-04	7.077E-05	9.440E-06	2.532E-06	6.632E-05	7.377E-05	7.372E-05	5.929E+03	7.109E+03
Po211	3.468E-04	3.959E-04	6.547E-04	1.509E-04	1.995E-05	5.387E-06	1.566E-04	1.820E-04	1.771E-04	2.749E+03	3.342E+03
Po212	2.892E-04	3.142E-04	6.050E-04	1.410E-04	1.874E-05	5.056E-06	1.321E-04	1.469E-04	1.471E-04	2.975E+03	3.560E+03
Po213	2.895E-04	3.145E-04	6.052E-04	1.410E-04	1.875E-05	5.057E-06	1.322E-04	1.470E-04	1.472E-04	2.974E+03	3.559E+03
Po214	2.897E-04	3.149E-04	6.054E-04	1.411E-04	1.875E-05	5.058E-06	1.323E-04	1.472E-04	1.473E-04	2.973E+03	3.558E+03
Po215	2.896E-04	3.147E-04	6.053E-04	1.411E-04	1.875E-05	5.058E-06	1.323E-04	1.471E-04	1.473E-04	2.974E+03	3.559E+03
Po216	2.894E-04	3.145E-04	6.051E-04	1.410E-04	1.875E-05	5.057E-06	1.322E-04	1.470E-04	1.472E-04	2.975E+03	3.559E+03
Po218	2.235E-04	2.428E-04	4.672E-04	1.089E-04	1.449E-05	3.902E-06	1.020E-04	1.135E-04	1.135E-04	3.853E+03	4.614E+03
Pr143	9.722E-07	1.469E-06	6.693E-07	1.283E-07	1.544E-08	4.163E-09	3.896E-07	5.917E-07	4.985E-07	1.225E+06	4.324E+06
Pr144	7.660E-03	9.794E-03	1.020E-02	2.273E-03	3.026E-04	8.262E-05	3.993E-03	5.058E-03	4.461E-03	1.765E+02	2.179E+02
Pr144m	1.736E-04	2.245E-04	2.159E-04	4.691E-05	6.070E-06	1.676E-06	8.714E-05	1.111E-04	9.970E-05	8.018E+03	1.074E+04
Pu236	2.150E-04	2.336E-04	4.501E-04	1.050E-04	1.397E-05	3.757E-06	9.837E-05	1.094E-04	1.094E-04	3.999E+03	4.791E+03
Pu238	1.946E-04	2.115E-04	4.079E-04	9.511E-05	1.267E-05	3.402E-06	8.918E-05	9.920E-05	9.908E-05	4.413E+03	5.291E+03
Pu239	1.284E-04	1.395E-04	2.684E-04	6.256E-05	8.351E-06	2.237E-06	5.859E-05	6.518E-05	6.513E-05	6.708E+03	8.045E+03
Pu240	1.029E-03	1.122E-03	2.185E-03	5.098E-04	6.774E-05	1.818E-05	4.800E-04	5.347E-04	5.316E-04	8.239E+02	9.899E+02
Pu241	2.678E-09	2.910E-09	5.597E-09	1.305E-09	1.744E-10	4.663E-11	1.222E-09	1.359E-09	1.358E-09	3.216E+08	3.860E+08
Pu242	8.642E-02	9.430E-02	1.839E-01	4.290E-02	5.697E-03	1.530E-03	4.043E-02	4.504E-02	4.475E-02	9.790E+00	1.176E+01
Pu243	2.638E-07	4.293E-07	1.312E-07	2.423E-08	2.827E-09	7.554E-10	9.941E-08	1.638E-07	1.339E-07	4.193E+06	2.097E+07
Pu244	2.004E+01	2.187E+01	4.271E+01	9.970E+00	1.324E+00	3.551E-01	9.398E+00	1.047E+01	1.040E+01	4.214E-02	5.068E-02
Pu246	2.966E-07	5.288E-07	1.042E-07	1.879E-08	2.193E-09	5.780E-10	1.073E-07	1.936E-07	1.504E-07	3.404E+06	1.702E+07
Ra223	1.930E-04	2.133E-04	3.918E-04	9.115E-05	1.213E-05	3.260E-06	8.758E-05	9.878E-05	9.798E-05	4.594E+03	5.522E+03
Ra224	1.847E-04	2.007E-04	3.860E-04	8.999E-05	1.199E-05	3.222E-06	8.433E-05	9.379E-05	9.379E-05	4.663E+03	5.587E+03
Ra225	4.544E-10	7.648E-10	2.007E-10	3.678E-11	4.278E-12	1.135E-12	1.685E-10	2.873E-10	2.306E-10	2.354E+09	1.177E+10
Ra226	1.010E-04	1.098E-04	2.111E-04	4.921E-05	6.580E-06	1.758E-06	4.607E-05	5.128E-05	5.121E-05	8.529E+03	1.024E+04
Rb86	4.019E-03	5.495E-03	4.147E-03	8.515E-04	1.076E-04	2.908E-05	1.849E-03	2.462E-03	2.195E-03	3.276E+02	6.190E+02
Rb87	3.841E-11	6.711E-11	1.485E-11	2.700E-12	3.145E-13	8.325E-14	1.404E-11	2.481E-11	1.949E-11	2.682E+10	1.341E+11
Re188	1.215E-03	1.611E-03	1.390E-03	2.963E-04	3.801E-05	1.042E-05	5.855E-04	7.669E-04	6.808E-04	1.117E+03	1.727E+03
Rh102	3.642E-03	4.965E-03	3.841E-03	8.021E-04	1.025E-04	2.781E-05	1.691E-03	2.266E-03	2.002E-03	3.625E+02	6.473E+02
Rh106	6.231E-03	8.190E-03	7.520E-03	1.635E-03	2.135E-04	5.867E-05	3.091E-03	4.001E-03	3.546E-03	2.198E+02	3.068E+02
Rn219	3.024E-04	3.351E-04	6.118E-04	1.422E-04	1.888E-05	5.094E-06	1.372E-04	1.550E-04	1.538E-04	2.942E+03	3.534E+03
Rn220	2.617E-04	2.846E-04	5.461E-04	1.273E-04	1.692E-05	4.561E-06	1.195E-04	1.329E-04	1.330E-04	3.296E+03	3.946E+03
Rn222	1.654E-04	1.799E-04	3.450E-04	8.041E-05	1.072E-05	2.878E-06	7.548E-05	8.404E-05	8.396E-05	5.218E+03	6.255E+03

Table 7.5-7 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Ru103	2.732E-04	4.199E-04	1.737E-04	3.295E-05	3.943E-06	1.064E-06	1.081E-04	1.656E-04	1.393E-04	4.286E+03	1.692E+04
S35	8.128E-14	1.726E-13	1.340E-14	2.403E-15	2.738E-16	7.907E-17	2.829E-14	6.020E-14	4.173E-14	1.043E+13	5.213E+13
Sb124	2.009E-01	2.596E-01	2.534E-01	5.543E-02	7.235E-03	1.987E-03	1.017E-01	1.296E-01	1.156E-01	6.934E+00	9.057E+00
Sb125	6.470E-04	9.689E-04	4.612E-04	8.883E-05	1.070E-05	2.843E-06	2.636E-04	3.898E-04	3.330E-04	1.858E+03	6.331E+03
Sb126	1.375E-02	1.957E-02	1.198E-02	2.390E-03	2.948E-04	7.953E-05	5.907E-03	8.390E-03	7.239E-03	9.196E+01	2.263E+02
Sb126m	5.038E-03	7.256E-03	4.255E-03	8.467E-04	1.045E-04	2.805E-05	2.144E-03	3.063E-03	2.656E-03	2.481E+02	6.417E+02
Sc46	5.530E-02	7.603E-02	5.564E-02	1.137E-02	1.431E-03	3.873E-04	2.513E-02	3.385E-02	2.998E-02	2.368E+01	4.648E+01
Se75	2.374E-05	3.733E-05	1.365E-05	2.555E-06	3.038E-07	8.292E-08	9.183E-06	1.449E-05	1.203E-05	4.822E+04	2.171E+05
Se79	9.503E-14	2.018E-13	1.567E-14	2.809E-15	3.201E-16	9.244E-17	3.308E-14	7.038E-14	4.879E-14	8.918E+12	4.459E+13
Sm145	6.380E-09	9.971E-09	3.735E-09	6.996E-10	8.323E-11	2.275E-11	2.476E-09	3.882E-09	3.234E-09	1.805E+08	7.911E+08
Sm146	6.242E-07	6.810E-07	1.352E-06	3.154E-07	4.163E-08	1.118E-08	3.021E-07	3.353E-07	3.313E-07	1.332E+06	1.610E+06
Sm147	2.985E-07	3.257E-07	6.465E-07	1.507E-07	1.980E-08	5.356E-09	1.448E-07	1.606E-07	1.585E-07	2.784E+06	3.361E+06
Sm148	4.536E-08	5.013E-08	9.737E-08	2.269E-08	2.977E-09	8.099E-10	2.227E-08	2.496E-08	2.441E-08	1.849E+07	2.222E+07
Sn113	4.138E-08	6.928E-08	2.032E-08	3.808E-09	4.530E-10	1.197E-10	1.572E-08	2.623E-08	2.111E-08	2.598E+07	1.299E+08
Sn123	3.078E-04	4.219E-04	3.150E-04	6.460E-05	8.158E-06	2.204E-06	1.411E-04	1.885E-04	1.678E-04	4.267E+03	8.168E+03
Sn126	6.855E-10	1.151E-09	3.046E-10	5.584E-11	6.495E-12	1.724E-12	2.544E-10	4.329E-10	3.478E-10	1.563E+09	7.816E+09
Sr85	7.113E-04	1.078E-03	4.799E-04	9.142E-05	1.097E-05	2.981E-06	2.809E-04	4.350E-04	3.639E-04	1.669E+03	6.038E+03
Sr89	2.921E-05	4.142E-05	2.596E-05	5.199E-06	6.442E-07	1.740E-07	1.263E-05	1.783E-05	1.543E-05	4.346E+04	1.035E+05
Sr90	3.610E-08	5.817E-08	1.891E-08	3.514E-09	4.135E-10	1.115E-10	1.373E-08	2.233E-08	1.832E-08	3.094E+07	1.547E+08
Ta182	5.997E-02	8.096E-02	6.380E-02	1.325E-02	1.678E-03	4.554E-04	2.814E-02	3.733E-02	3.292E-02	2.223E+01	3.953E+01
Tb160	2.674E-02	3.659E-02	2.698E-02	5.531E-03	6.948E-04	1.881E-04	1.218E-02	1.650E-02	1.446E-02	4.920E+01	9.569E+01
Tc99	1.109E-10	1.896E-10	4.634E-11	8.466E-12	9.852E-13	2.611E-13	4.086E-11	7.074E-11	5.625E-11	9.492E+09	4.746E+10
Tc99m	9.310E-10	1.964E-09	1.622E-10	2.915E-11	3.327E-12	9.543E-13	3.248E-10	6.863E-10	4.778E-10	9.165E+08	4.582E+09
Te121	7.304E-04	1.107E-03	4.924E-04	9.378E-05	1.125E-05	3.058E-06	2.884E-04	4.467E-04	3.736E-04	1.625E+03	5.887E+03
Te121m	1.188E-03	1.625E-03	1.224E-03	2.512E-04	3.175E-05	8.575E-06	5.459E-04	7.276E-04	6.484E-04	1.108E+03	2.099E+03
Te123m	8.572E-10	1.819E-09	1.421E-10	2.549E-11	2.905E-12	8.381E-13	2.984E-10	6.345E-10	4.401E-10	9.894E+08	4.947E+09
Te125m	2.842E-12	6.036E-12	4.685E-13	8.401E-14	9.573E-15	2.765E-15	9.892E-13	2.105E-12	1.459E-12	2.982E+11	1.491E+12
Te127	2.061E-06	3.225E-06	1.203E-06	2.253E-07	2.679E-08	7.316E-09	7.992E-07	1.255E-06	1.045E-06	5.582E+05	2.460E+06
Te127m	2.162E-07	3.225E-07	1.567E-07	3.024E-08	3.648E-09	9.672E-10	8.845E-08	1.302E-07	1.114E-07	5.582E+06	1.861E+07
Te129	4.045E-04	5.585E-04	4.028E-04	8.232E-05	1.037E-05	2.803E-06	1.835E-04	2.479E-04	2.192E-04	3.223E+03	6.421E+03
Te129m	1.421E-04	2.045E-04	1.181E-04	2.330E-05	2.851E-06	7.686E-07	5.978E-05	8.620E-05	7.432E-05	8.801E+03	2.342E+04
Th227	1.640E-04	1.809E-04	3.346E-04	7.785E-05	1.036E-05	2.786E-06	7.454E-05	8.391E-05	8.333E-05	5.380E+03	6.461E+03

Table 7.5-7 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Th228	1.548E-04	1.682E-04	3.237E-04	7.546E-05	1.006E-05	2.700E-06	7.069E-05	7.861E-05	7.858E-05	5.561E+03	6.666E+03
Th229	1.075E-04	1.169E-04	2.241E-04	5.225E-05	6.983E-06	1.867E-06	4.898E-05	5.455E-05	5.446E-05	8.031E+03	9.639E+03
Th230	9.363E-05	1.017E-04	1.956E-04	4.560E-05	6.100E-06	1.628E-06	4.269E-05	4.752E-05	4.745E-05	9.203E+03	1.105E+04
Th231	1.824E-09	3.094E-09	7.849E-10	1.436E-10	1.671E-11	4.431E-12	6.744E-10	1.158E-09	9.254E-10	5.819E+08	2.909E+09
Th232	4.428E-05	4.824E-05	9.293E-05	2.168E-05	2.918E-06	7.696E-07	2.031E-05	2.269E-05	2.255E-05	1.937E+04	2.339E+04
Th234	2.592E-12	5.505E-12	4.273E-13	7.661E-14	8.730E-15	2.521E-15	9.021E-13	1.919E-12	1.331E-12	3.270E+11	1.635E+12
Tl206	4.833E-07	6.824E-07	4.242E-07	8.413E-08	1.035E-08	2.827E-09	2.063E-07	2.947E-07	2.522E-07	2.638E+06	6.366E+06
Tl207	3.963E-05	5.625E-05	3.445E-05	6.838E-06	8.417E-07	2.290E-07	1.691E-05	2.416E-05	2.072E-05	3.200E+04	7.860E+04
Tl208	1.409E+00	1.754E+00	2.036E+00	4.677E-01	6.262E-02	1.796E-02	7.707E-01	9.526E-01	8.510E-01	8.840E-01	1.002E+00
Tl209	2.821E-01	3.656E-01	3.491E-01	7.575E-02	9.787E-03	2.700E-03	1.415E-01	1.802E-01	1.618E-01	4.923E+00	6.668E+00
Tm168	1.097E-02	1.540E-02	9.945E-03	1.994E-03	2.470E-04	6.718E-05	4.759E-03	6.719E-03	5.773E-03	1.169E+02	2.679E+02
Tm170	1.071E-06	1.614E-06	7.461E-07	1.433E-07	1.726E-08	4.654E-09	4.304E-07	6.517E-07	5.495E-07	1.115E+06	3.868E+06
Tm171	7.772E-21	1.651E-20	1.281E-21	2.298E-22	2.618E-23	7.561E-24	2.705E-21	5.756E-21	3.990E-21	1.090E+20	5.452E+20
U232	1.443E-04	1.567E-04	3.016E-04	7.032E-05	9.379E-06	2.516E-06	6.586E-05	7.325E-05	7.321E-05	5.968E+03	7.155E+03
U233	1.035E-04	1.124E-04	2.161E-04	5.039E-05	6.737E-06	1.801E-06	4.718E-05	5.251E-05	5.244E-05	8.328E+03	9.997E+03
U234	1.004E-04	1.091E-04	2.097E-04	4.890E-05	6.538E-06	1.747E-06	4.578E-05	5.095E-05	5.088E-05	8.583E+03	1.030E+04
U235	6.624E-05	7.210E-05	1.384E-04	3.226E-05	4.325E-06	1.149E-06	3.025E-05	3.373E-05	3.362E-05	1.301E+04	1.566E+04
U236	8.989E-05	9.777E-05	1.884E-04	4.393E-05	5.879E-06	1.566E-06	4.118E-05	4.586E-05	4.573E-05	9.555E+03	1.149E+04
U237	6.818E-07	1.156E-06	2.932E-07	5.364E-08	6.242E-09	1.655E-09	2.520E-07	4.327E-07	3.458E-07	1.557E+06	7.787E+06
U238	7.916E-03	8.642E-03	1.689E-02	3.942E-03	5.237E-04	1.404E-04	3.716E-03	4.142E-03	4.110E-03	1.066E+02	1.282E+02
U239	9.689E-05	1.368E-04	8.554E-05	1.702E-05	2.095E-06	5.671E-07	4.146E-05	5.899E-05	5.071E-05	1.316E+04	3.174E+04
U240	1.235E-09	2.121E-09	5.073E-10	9.257E-11	1.078E-11	2.854E-12	4.542E-10	7.895E-10	6.265E-10	8.487E+08	4.244E+09
W181	1.158E-12	2.460E-12	1.909E-13	3.423E-14	3.901E-15	1.127E-15	4.031E-13	8.577E-13	5.945E-13	7.318E+11	3.659E+12
W185	3.681E-09	6.085E-09	1.737E-09	3.198E-10	3.729E-11	9.940E-12	1.377E-09	2.305E-09	1.867E-09	2.958E+08	1.479E+09
W188	8.418E-09	1.494E-08	3.016E-09	5.450E-10	6.357E-11	1.677E-11	3.052E-09	5.481E-09	4.269E-09	1.205E+08	6.024E+08
Xe127	5.931E-06	9.801E-06	2.805E-06	5.170E-07	6.024E-08	1.600E-08	2.221E-06	3.714E-06	3.011E-06	1.837E+05	9.183E+05
Xe131m	1.971E-11	4.186E-11	3.249E-12	5.826E-13	6.639E-14	1.917E-14	6.860E-12	1.460E-11	1.012E-11	4.300E+10	2.150E+11
Y88	4.333E-01	5.546E-01	5.541E-01	1.213E-01	1.577E-02	4.369E-03	2.200E-01	2.795E-01	2.508E-01	3.246E+00	4.120E+00
Y89m	1.727E-02	2.398E-02	1.612E-02	3.242E-03	4.006E-04	1.075E-04	7.496E-03	1.052E-02	9.114E-03	7.507E+01	1.675E+02
Y90	3.455E-04	4.686E-04	3.658E-04	7.640E-05	9.728E-06	2.646E-06	1.605E-04	2.154E-04	1.895E-04	3.842E+03	6.804E+03
Y90m	1.812E-04	2.828E-04	1.069E-04	2.004E-05	2.385E-06	6.514E-07	7.039E-05	1.102E-04	9.190E-05	6.365E+03	2.763E+04
Y91	2.404E-04	3.242E-04	2.545E-04	5.297E-05	6.698E-06	1.822E-06	1.130E-04	1.507E-04	1.317E-04	5.552E+03	9.881E+03

Table 7.5-7 – [redacted] SIA Unit Dose Rates and Maximum Activity Results, Exclusive Use (8 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)						HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)	
	Package Surface			Vehicle Surface	2-Meter	Driver Cab	1-Meter			Open Transport	Closed Transport
	Top	Bottom	Side				Top	Bottom	Side		
Zn65	2.286E-02	3.125E-02	2.362E-02	4.850E-03	6.132E-04	1.656E-04	1.052E-02	1.401E-02	1.249E-02	5.759E+01	1.087E+02
Zr88	2.749E-05	4.501E-05	1.326E-05	2.442E-06	2.838E-07	7.544E-08	1.031E-05	1.712E-05	1.395E-05	3.999E+04	1.999E+05
Zr90m	8.706E-01	1.102E+00	1.201E+00	2.702E-01	3.618E-02	9.878E-03	4.633E-01	5.811E-01	5.123E-01	1.498E+00	1.822E+00
Zr95	4.761E-03	6.863E-03	3.873E-03	7.564E-04	9.215E-05	2.478E-05	1.988E-03	2.879E-03	2.453E-03	2.623E+02	7.263E+02

Table 7.5-8 - [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Ac225	1.989E-04	2.165E-04	4.142E-04	5.306E-05	9.073E-05	1.011E-04	1.010E-04	1.696E+03
Ac227	1.552E-06	1.687E-06	3.240E-06	4.157E-07	7.077E-07	7.878E-07	7.868E-07	2.165E+05
Ac228	3.550E-02	4.703E-02	4.063E-02	4.637E-03	1.706E-02	2.237E-02	1.986E-02	1.941E+01
Ag108	9.085E-05	1.301E-04	7.868E-05	8.316E-06	3.915E-05	5.544E-05	4.798E-05	1.082E+04
Ag108m	5.967E-03	8.690E-03	4.696E-03	4.808E-04	2.476E-03	3.604E-03	3.073E-03	1.872E+02
Ag110	1.231E-03	1.642E-03	1.399E-03	1.605E-04	5.924E-04	7.797E-04	6.884E-04	5.606E+02
Ag110m	9.865E-02	1.311E-01	1.120E-01	1.274E-02	4.699E-02	6.225E-02	5.496E-02	7.066E+00
Am241	1.634E-04	1.775E-04	3.415E-04	4.378E-05	7.459E-05	8.295E-05	8.293E-05	2.056E+03
Am242	4.057E-08	6.442E-08	2.272E-08	2.209E-09	1.559E-08	2.498E-08	2.062E-08	2.794E+07
Am242m	1.418E-06	1.545E-06	2.992E-06	3.836E-07	6.560E-07	7.302E-07	7.276E-07	2.346E+05
Am243	1.412E-04	1.534E-04	2.951E-04	3.784E-05	6.444E-05	7.168E-05	7.164E-05	2.378E+03
Am245	5.773E-07	9.003E-07	3.600E-07	3.573E-08	2.268E-07	3.553E-07	2.952E-07	1.999E+06
Am246	3.057E-03	4.426E-03	2.454E-03	2.517E-04	1.269E-03	1.850E-03	1.585E-03	3.575E+02
At217	2.896E-04	3.147E-04	6.052E-04	7.752E-05	1.323E-04	1.471E-04	1.472E-04	1.161E+03
Au198	2.735E-04	4.117E-04	1.955E-04	1.998E-05	1.117E-04	1.666E-04	1.417E-04	4.372E+03
Ba133	2.533E-05	4.149E-05	1.221E-05	1.165E-06	9.496E-06	1.578E-05	1.285E-05	4.338E+04
Ba137m	1.411E-03	2.101E-03	1.028E-03	1.035E-04	5.789E-04	8.486E-04	7.271E-04	8.567E+02
Ba140	1.931E-04	2.934E-04	1.292E-04	1.280E-05	7.619E-05	1.181E-04	9.875E-05	6.135E+03
Be10	3.288E-08	5.299E-08	1.722E-08	1.661E-09	1.250E-08	2.034E-08	1.668E-08	3.397E+07
Bi207	5.428E-02	7.293E-02	5.982E-02	6.715E-03	2.574E-02	3.377E-02	3.016E-02	1.340E+01
Bi210	3.783E-06	5.559E-06	2.913E-06	2.984E-07	1.560E-06	2.299E-06	1.957E-06	3.016E+05
Bi211	2.873E-04	3.142E-04	5.951E-04	7.617E-05	1.310E-04	1.463E-04	1.461E-04	1.182E+03
Bi212	6.342E-03	8.279E-03	7.692E-03	8.936E-04	3.130E-03	4.020E-03	3.601E-03	1.007E+02
Bi213	2.710E-04	3.810E-04	2.555E-04	2.760E-05	1.197E-04	1.652E-04	1.449E-04	3.261E+03
Bi214	1.822E-01	2.350E-01	2.325E-01	2.763E-02	9.283E-02	1.183E-01	1.051E-01	3.258E+00
Bk247	3.711E-07	6.614E-07	1.304E-07	1.222E-08	1.343E-07	2.422E-07	1.882E-07	2.721E+06
Bk249	1.247E-05	1.360E-05	2.650E-05	3.397E-06	5.826E-06	6.489E-06	6.451E-06	2.649E+04
Bk250	2.699E-02	3.707E-02	2.711E-02	2.944E-03	1.222E-02	1.652E-02	1.460E-02	3.057E+01
C14	5.527E-14	1.174E-13	9.112E-15	8.389E-16	1.924E-14	4.093E-14	2.837E-14	1.533E+13
Ca45	1.630E-11	2.912E-11	5.768E-12	5.414E-13	5.907E-12	1.067E-11	8.272E-12	6.181E+10
Cd113	3.050E-10	5.160E-10	1.323E-10	1.256E-11	1.129E-10	1.934E-10	1.547E-10	3.488E+09
Cd113m	3.774E-08	6.057E-08	2.016E-08	1.948E-09	1.439E-08	2.332E-08	1.916E-08	2.972E+07
Cd115m	1.152E-03	1.562E-03	1.190E-03	1.309E-04	5.316E-04	7.171E-04	6.257E-04	6.876E+02
Ce141	1.353E-08	2.210E-08	6.863E-09	6.612E-10	5.122E-09	8.441E-09	6.869E-09	8.143E+07
Ce144	2.938E-10	5.464E-10	9.662E-11	9.115E-12	1.062E-10	1.984E-10	1.498E-10	3.294E+09
Cf249	3.434E-04	3.866E-04	6.872E-04	8.776E-05	1.568E-04	1.793E-04	1.761E-04	1.026E+03
Cf250	1.854E+01	2.027E+01	3.980E+01	5.111E+00	8.769E+00	9.776E+00	9.682E+00	1.761E-02
Cf251	1.984E-04	2.156E-04	4.146E-04	5.313E-05	9.058E-05	1.007E-04	1.008E-04	1.694E+03
Cf252	8.514E+02	9.285E+02	1.807E+03	2.315E+02	3.972E+02	4.422E+02	4.400E+02	3.888E-04
Cf253	6.853E-07	7.444E-07	1.433E-06	1.836E-07	3.129E-07	3.479E-07	3.481E-07	4.902E+05
Cf254	2.645E+04	2.892E+04	5.678E+04	7.291E+03	1.251E+04	1.395E+04	1.381E+04	1.234E-05
Cl36	3.738E-07	5.748E-07	2.391E-07	2.358E-08	1.466E-07	2.289E-07	1.909E-07	3.132E+06
Cm240	9.415E-04	1.026E-03	1.990E-03	2.548E-04	4.365E-04	4.858E-04	4.842E-04	3.532E+02
Cm242	1.403E-03	1.530E-03	2.974E-03	3.811E-04	6.530E-04	7.271E-04	7.237E-04	2.361E+02

Table 7.5-8 - [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Cm243	2.018E-04	2.195E-04	4.213E-04	5.399E-05	9.213E-05	1.025E-04	1.025E-04	1.667E+03
Cm244	2.705E-02	2.951E-02	5.747E-02	7.366E-03	1.263E-02	1.407E-02	1.399E-02	1.222E+01
Cm245	2.778E-04	3.024E-04	5.852E-04	7.502E-05	1.282E-04	1.426E-04	1.422E-04	1.200E+03
Cm246	6.081E+00	6.634E+00	1.293E+01	1.657E+00	2.842E+00	3.165E+00	3.146E+00	5.432E-02
Cm247	2.517E-04	3.394E-04	3.178E-04	3.828E-05	1.054E-04	1.417E-04	1.276E-04	2.351E+03
Cm248	1.891E+03	2.063E+03	4.023E+03	5.159E+02	8.847E+02	9.855E+02	9.793E+02	1.745E-04
Cm249	3.662E-05	5.477E-05	2.624E-05	2.633E-06	1.490E-05	2.211E-05	1.884E-05	3.287E+04
Cm250	2.428E+00	3.030E+00	3.504E+00	4.438E-01	1.327E+00	1.647E+00	1.466E+00	2.028E-01
Co57	3.479E-06	5.122E-06	2.618E-06	2.642E-07	1.413E-06	2.099E-06	1.803E-06	3.407E+05
Co58	1.136E-02	1.590E-02	1.045E-02	1.115E-03	4.951E-03	6.971E-03	6.001E-03	8.069E+01
Co60	1.244E-01	1.677E-01	1.327E-01	1.469E-02	5.850E-02	7.754E-02	6.831E-02	6.126E+00
Cr51	2.800E-06	4.585E-06	1.351E-06	1.289E-07	1.050E-06	1.744E-06	1.421E-06	3.926E+05
Cs134	1.195E-02	1.672E-02	1.122E-02	1.209E-03	5.252E-03	7.347E-03	6.359E-03	7.443E+01
Cs135	2.647E-13	5.549E-13	4.769E-14	4.403E-15	9.244E-14	1.941E-13	1.358E-13	3.244E+12
Cs137	2.623E-07	3.867E-07	2.002E-07	2.050E-08	1.080E-07	1.596E-07	1.356E-07	4.390E+06
Cu64	8.985E-04	1.241E-03	9.042E-04	9.984E-05	4.036E-04	5.630E-04	4.871E-04	9.015E+02
Dy159	2.865E-10	4.695E-10	1.379E-10	1.316E-11	1.074E-10	1.785E-10	1.454E-10	3.834E+09
Es252	1.356E-03	1.932E-03	1.152E-03	1.200E-04	5.729E-04	8.220E-04	7.037E-04	7.500E+02
Es253	2.675E-03	2.923E-03	5.726E-03	7.351E-04	1.261E-03	1.405E-03	1.393E-03	1.224E+02
Es254	1.088E-03	1.188E-03	2.321E-03	2.978E-04	5.102E-04	5.684E-04	5.645E-04	3.022E+02
Es254m	1.212E+01	1.326E+01	2.603E+01	3.342E+00	5.736E+00	6.395E+00	6.333E+00	2.693E-02
Eu149	9.959E-06	1.526E-05	6.461E-06	6.383E-07	3.906E-06	6.107E-06	5.089E-06	1.179E+05
Eu150	1.981E-02	2.672E-02	2.135E-02	2.384E-03	9.248E-03	1.238E-02	1.090E-02	3.776E+01
Eu152	4.828E-02	6.479E-02	5.289E-02	5.910E-03	2.251E-02	3.021E-02	2.658E-02	1.523E+01
Eu154	4.778E-02	6.427E-02	5.133E-02	5.715E-03	2.251E-02	2.989E-02	2.627E-02	1.575E+01
Eu155	2.162E-10	4.589E-10	3.588E-11	3.304E-12	7.528E-11	1.600E-10	1.110E-10	3.923E+09
Fe55	1.299E-18	2.759E-18	2.142E-19	1.972E-20	4.522E-19	9.621E-19	6.670E-19	6.523E+17
Fe59	5.991E-02	8.089E-02	6.370E-02	7.046E-03	2.812E-02	3.728E-02	3.288E-02	1.277E+01
Fr221	2.646E-04	2.878E-04	5.524E-04	7.076E-05	1.208E-04	1.344E-04	1.345E-04	1.272E+03
Fr223	6.480E-05	9.258E-05	5.461E-05	5.674E-06	2.733E-05	3.935E-05	3.361E-05	1.586E+04
Gd152	1.267E-07	1.387E-07	2.748E-07	3.511E-08	6.188E-08	6.882E-08	6.776E-08	2.564E+06
Gd153	2.146E-10	4.559E-10	3.539E-11	3.258E-12	7.471E-11	1.590E-10	1.102E-10	3.948E+09
Hf175	2.661E-05	4.336E-05	1.312E-05	1.255E-06	1.001E-05	1.653E-05	1.350E-05	4.151E+04
Hf181	1.638E-04	2.560E-04	9.601E-05	9.352E-06	6.359E-05	9.968E-05	8.305E-05	7.031E+03
Hg203	1.008E-06	1.797E-06	3.543E-07	3.320E-08	3.648E-07	6.580E-07	5.113E-07	1.002E+06
Ho166m	1.306E-02	1.836E-02	1.179E-02	1.250E-03	5.648E-03	7.992E-03	6.867E-03	7.197E+01
I129	2.780E-14	5.905E-14	4.583E-15	4.220E-16	9.676E-15	2.059E-14	1.427E-14	3.049E+13
I131	2.271E-04	3.376E-04	1.668E-04	1.690E-05	9.292E-05	1.374E-04	1.168E-04	5.326E+03
In113m	1.822E-05	2.983E-05	8.789E-06	8.386E-07	6.830E-06	1.135E-05	9.245E-06	6.034E+04
In114	2.341E-04	3.184E-04	2.421E-04	2.670E-05	1.083E-04	1.458E-04	1.275E-04	3.370E+03
In114m	1.805E-04	2.620E-04	1.435E-04	1.472E-05	7.483E-05	1.093E-04	9.291E-05	6.113E+03
In115	1.087E-08	1.774E-08	5.397E-09	5.176E-10	4.099E-09	6.760E-09	5.513E-09	1.015E+08
In115m	1.303E-05	2.133E-05	6.294E-06	6.007E-07	4.886E-06	8.112E-06	6.611E-06	8.440E+04
Ir194	1.963E-03	2.617E-03	2.211E-03	2.509E-04	9.363E-04	1.234E-03	1.094E-03	3.588E+02

Table 7.5-8 - [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
K40	1.415E-02	1.876E-02	1.620E-02	1.834E-03	6.678E-03	8.959E-03	7.855E-03	4.909E+01
K42	5.473E-02	7.092E-02	6.786E-02	7.933E-03	2.747E-02	3.500E-02	3.141E-02	1.134E+01
Kr85	3.403E-06	5.167E-06	2.280E-06	2.259E-07	1.342E-06	2.081E-06	1.740E-06	3.483E+05
La140	3.336E-01	4.300E-01	4.234E-01	5.009E-02	1.696E-01	2.151E-01	1.929E-01	1.797E+00
Lu177	1.985E-07	3.439E-07	7.875E-08	7.437E-09	7.273E-08	1.275E-07	1.007E-07	5.234E+06
Lu177m	3.943E-05	6.175E-05	2.300E-05	2.243E-06	1.529E-05	2.405E-05	2.001E-05	2.915E+04
Mn54	9.664E-03	1.364E-02	8.482E-03	8.880E-04	4.124E-03	5.892E-03	5.042E-03	1.014E+02
Na22	8.013E-02	1.074E-01	8.644E-02	9.629E-03	3.804E-02	5.042E-02	4.408E-02	9.346E+00
Na24	1.542E+00	1.930E+00	2.191E+00	2.727E-01	8.340E-01	1.037E+00	9.253E-01	3.301E-01
Nb91	2.330E-06	3.532E-06	1.571E-06	1.558E-07	9.199E-07	1.425E-06	1.192E-06	5.097E+05
Nb94	1.447E-02	2.058E-02	1.239E-02	1.291E-03	6.132E-03	8.799E-03	7.519E-03	6.971E+01
Nb95	4.817E-03	6.944E-03	3.919E-03	4.038E-04	2.011E-03	2.912E-03	2.482E-03	2.229E+02
Nb95m	1.372E-06	2.117E-06	9.138E-07	9.217E-08	5.463E-07	8.480E-07	7.028E-07	8.503E+05
Nd144	2.392E-08	2.672E-08	5.027E-08	6.435E-09	1.179E-08	1.334E-08	1.296E-08	1.399E+07
Ni59	5.490E-10	8.323E-10	3.703E-10	3.671E-11	2.168E-10	3.358E-10	2.808E-10	2.163E+09
Np235	3.069E-09	3.339E-09	6.406E-09	8.219E-10	1.400E-09	1.559E-09	1.556E-09	1.095E+08
Np237	9.582E-05	1.041E-04	2.001E-04	2.569E-05	4.369E-05	4.862E-05	4.856E-05	3.503E+03
Np238	1.764E-02	2.424E-02	1.770E-02	1.920E-03	7.982E-03	1.079E-02	9.541E-03	4.687E+01
Np239	1.493E-06	2.494E-06	6.782E-07	6.458E-08	5.557E-07	9.400E-07	7.573E-07	7.218E+05
Np240	1.210E-02	1.688E-02	1.125E-02	1.198E-03	5.279E-03	7.380E-03	6.407E-03	7.510E+01
Np240m	7.644E-03	1.014E-02	8.764E-03	1.000E-03	3.663E-03	4.833E-03	4.275E-03	8.999E+01
Os185	2.541E-03	3.689E-03	2.034E-03	2.091E-04	1.062E-03	1.538E-03	1.317E-03	4.304E+02
Os194	1.174E-20	2.493E-20	1.935E-21	1.782E-22	4.085E-21	8.692E-21	6.026E-21	7.220E+19
P32	5.812E-05	8.143E-05	5.420E-05	5.812E-06	2.560E-05	3.563E-05	3.097E-05	1.548E+04
P33	1.080E-11	1.946E-11	3.693E-12	3.460E-13	3.901E-12	7.104E-12	5.480E-12	9.250E+10
Pa231	1.136E-04	1.248E-04	2.336E-04	2.994E-05	5.165E-05	5.795E-05	5.762E-05	3.006E+03
Pa233	1.804E-05	2.928E-05	9.052E-06	8.676E-07	6.807E-06	1.118E-05	9.150E-06	6.148E+04
Pa234	3.683E-02	4.935E-02	4.043E-02	4.556E-03	1.730E-02	2.309E-02	2.034E-02	1.975E+01
Pa234m	1.067E-03	1.427E-03	1.190E-03	1.345E-04	5.078E-04	6.675E-04	5.940E-04	6.689E+02
Pb209	6.601E-08	1.047E-07	3.714E-08	3.611E-09	2.538E-08	4.062E-08	3.355E-08	1.720E+07
Pb210	4.505E-13	4.919E-13	9.513E-13	1.227E-13	2.084E-13	2.335E-13	2.313E-13	7.332E+11
Pb211	4.984E-04	7.034E-04	4.433E-04	4.670E-05	2.146E-04	3.039E-04	2.616E-04	1.927E+03
Pb212	1.500E-06	2.532E-06	6.556E-07	6.226E-08	5.556E-07	9.497E-07	7.608E-07	7.109E+05
Pb214	1.248E-04	1.810E-04	1.005E-04	1.038E-05	5.203E-05	7.600E-05	6.457E-05	8.667E+03
Pm145	8.396E-18	1.055E-17	1.186E-17	1.483E-18	4.529E-18	5.648E-18	5.026E-18	6.067E+16
Pm146	2.888E-03	4.179E-03	2.317E-03	2.383E-04	1.202E-03	1.746E-03	1.487E-03	3.777E+02
Pm147	1.461E-12	2.747E-12	4.358E-13	4.072E-14	5.230E-13	9.902E-13	7.436E-13	6.554E+11
Pm148	3.265E-02	4.341E-02	3.692E-02	4.169E-03	1.534E-02	2.062E-02	1.807E-02	2.159E+01
Pm148m	1.629E-02	2.277E-02	1.542E-02	1.655E-03	7.222E-03	9.945E-03	8.721E-03	5.440E+01
Po209	4.545E-05	6.417E-05	3.989E-05	4.176E-06	1.940E-05	2.771E-05	2.371E-05	2.155E+04
Po210	1.453E-04	1.578E-04	3.036E-04	3.893E-05	6.632E-05	7.377E-05	7.372E-05	2.312E+03
Po211	3.468E-04	3.959E-04	6.547E-04	8.269E-05	1.566E-04	1.820E-04	1.771E-04	1.088E+03
Po212	2.892E-04	3.142E-04	6.050E-04	7.749E-05	1.321E-04	1.469E-04	1.471E-04	1.161E+03
Po213	2.895E-04	3.145E-04	6.052E-04	7.751E-05	1.322E-04	1.470E-04	1.472E-04	1.161E+03

Table 7.5-8 - [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Po214	2.897E-04	3.149E-04	6.054E-04	7.753E-05	1.323E-04	1.472E-04	1.473E-04	1.161E+03
Po215	2.896E-04	3.147E-04	6.053E-04	7.752E-05	1.323E-04	1.471E-04	1.473E-04	1.161E+03
Po216	2.894E-04	3.145E-04	6.051E-04	7.751E-05	1.322E-04	1.470E-04	1.472E-04	1.161E+03
Po218	2.235E-04	2.428E-04	4.672E-04	5.986E-05	1.020E-04	1.135E-04	1.135E-04	1.504E+03
Pr143	9.722E-07	1.469E-06	6.693E-07	6.706E-08	3.896E-07	5.917E-07	4.985E-07	1.225E+06
Pr144	7.660E-03	9.794E-03	1.020E-02	1.234E-03	3.993E-03	5.058E-03	4.461E-03	7.292E+01
Pr144m	1.736E-04	2.245E-04	2.159E-04	2.530E-05	8.714E-05	1.111E-04	9.970E-05	3.557E+03
Pu236	2.150E-04	2.336E-04	4.501E-04	5.769E-05	9.837E-05	1.094E-04	1.094E-04	1.560E+03
Pu238	1.946E-04	2.115E-04	4.079E-04	5.229E-05	8.918E-05	9.920E-05	9.908E-05	1.721E+03
Pu239	1.284E-04	1.395E-04	2.684E-04	3.442E-05	5.859E-05	6.518E-05	6.513E-05	2.615E+03
Pu240	1.029E-03	1.122E-03	2.185E-03	2.802E-04	4.800E-04	5.347E-04	5.316E-04	3.212E+02
Pu241	2.678E-09	2.910E-09	5.597E-09	7.182E-10	1.222E-09	1.359E-09	1.358E-09	1.253E+08
Pu242	8.642E-02	9.430E-02	1.839E-01	2.358E-02	4.043E-02	4.504E-02	4.475E-02	3.817E+00
Pu243	2.638E-07	4.293E-07	1.312E-07	1.256E-08	9.941E-08	1.638E-07	1.339E-07	4.193E+06
Pu244	2.004E+01	2.187E+01	4.271E+01	5.480E+00	9.398E+00	1.047E+01	1.040E+01	1.642E-02
Pu246	2.966E-07	5.288E-07	1.042E-07	9.758E-09	1.073E-07	1.936E-07	1.504E-07	3.404E+06
Ra223	1.930E-04	2.133E-04	3.918E-04	5.008E-05	8.758E-05	9.878E-05	9.798E-05	1.797E+03
Ra224	1.847E-04	2.007E-04	3.860E-04	4.947E-05	8.433E-05	9.379E-05	9.379E-05	1.819E+03
Ra225	4.544E-10	7.648E-10	2.007E-10	1.907E-11	1.685E-10	2.873E-10	2.306E-10	2.354E+09
Ra226	1.010E-04	1.098E-04	2.111E-04	2.709E-05	4.607E-05	5.128E-05	5.121E-05	3.322E+03
Rb86	4.019E-03	5.495E-03	4.147E-03	4.533E-04	1.849E-03	2.462E-03	2.195E-03	1.985E+02
Rb87	3.841E-11	6.711E-11	1.485E-11	1.401E-12	1.404E-11	2.481E-11	1.949E-11	2.682E+10
Re188	1.215E-03	1.611E-03	1.390E-03	1.591E-04	5.855E-04	7.669E-04	6.808E-04	5.658E+02
Rh102	3.642E-03	4.965E-03	3.841E-03	4.281E-04	1.691E-03	2.266E-03	2.002E-03	2.102E+02
Rh106	6.231E-03	8.190E-03	7.520E-03	8.823E-04	3.091E-03	4.001E-03	3.546E-03	1.020E+02
Rn219	3.024E-04	3.351E-04	6.118E-04	7.811E-05	1.372E-04	1.550E-04	1.538E-04	1.152E+03
Rn220	2.617E-04	2.846E-04	5.461E-04	6.994E-05	1.195E-04	1.329E-04	1.330E-04	1.287E+03
Rn222	1.654E-04	1.799E-04	3.450E-04	4.421E-05	7.548E-05	8.404E-05	8.396E-05	2.036E+03
Ru103	2.732E-04	4.199E-04	1.737E-04	1.714E-05	1.081E-04	1.656E-04	1.393E-04	4.286E+03
S35	8.128E-14	1.726E-13	1.340E-14	1.234E-15	2.829E-14	6.020E-14	4.173E-14	1.043E+13
Sb124	2.009E-01	2.596E-01	2.534E-01	2.991E-02	1.017E-01	1.296E-01	1.156E-01	3.009E+00
Sb125	6.470E-04	9.689E-04	4.612E-04	4.627E-05	2.636E-04	3.898E-04	3.330E-04	1.858E+03
Sb126	1.375E-02	1.957E-02	1.198E-02	1.262E-03	5.907E-03	8.390E-03	7.239E-03	7.134E+01
Sb126m	5.038E-03	7.256E-03	4.255E-03	4.457E-04	2.144E-03	3.063E-03	2.656E-03	2.019E+02
Sc46	5.530E-02	7.603E-02	5.564E-02	6.045E-03	2.513E-02	3.385E-02	2.998E-02	1.489E+01
Se75	2.374E-05	3.733E-05	1.365E-05	1.328E-06	9.183E-06	1.449E-05	1.203E-05	4.822E+04
Se79	9.503E-14	2.018E-13	1.567E-14	1.443E-15	3.308E-14	7.038E-14	4.879E-14	8.918E+12
Sm145	6.380E-09	9.971E-09	3.735E-09	3.635E-10	2.476E-09	3.882E-09	3.234E-09	1.805E+08
Sm146	6.242E-07	6.810E-07	1.352E-06	1.728E-07	3.021E-07	3.353E-07	3.313E-07	5.208E+05
Sm147	2.985E-07	3.257E-07	6.465E-07	8.258E-08	1.448E-07	1.606E-07	1.585E-07	1.090E+06
Sm148	4.536E-08	5.013E-08	9.737E-08	1.246E-08	2.227E-08	2.496E-08	2.441E-08	7.223E+06
Sn113	4.138E-08	6.928E-08	2.032E-08	1.981E-09	1.572E-08	2.623E-08	2.111E-08	2.598E+07
Sn123	3.078E-04	4.219E-04	3.150E-04	3.438E-05	1.411E-04	1.885E-04	1.678E-04	2.618E+03
Sn126	6.855E-10	1.151E-09	3.046E-10	2.895E-11	2.544E-10	4.329E-10	3.478E-10	1.563E+09

Table 7.5-8 - [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Sr85	7.113E-04	1.078E-03	4.799E-04	4.759E-05	2.809E-04	4.350E-04	3.639E-04	1.669E+03
Sr89	2.921E-05	4.142E-05	2.596E-05	2.749E-06	1.263E-05	1.783E-05	1.543E-05	3.274E+04
Sr90	3.610E-08	5.817E-08	1.891E-08	1.824E-09	1.373E-08	2.233E-08	1.832E-08	3.094E+07
Ta182	5.997E-02	8.096E-02	6.380E-02	7.059E-03	2.814E-02	3.733E-02	3.292E-02	1.275E+01
Tb160	2.674E-02	3.659E-02	2.698E-02	2.940E-03	1.218E-02	1.650E-02	1.446E-02	3.061E+01
Tc99	1.109E-10	1.896E-10	4.634E-11	4.390E-12	4.086E-11	7.074E-11	5.625E-11	9.492E+09
Tc99m	9.310E-10	1.964E-09	1.622E-10	1.498E-11	3.248E-10	6.863E-10	4.778E-10	9.165E+08
Te121	7.304E-04	1.107E-03	4.924E-04	4.881E-05	2.884E-04	4.467E-04	3.736E-04	1.625E+03
Te121m	1.188E-03	1.625E-03	1.224E-03	1.337E-04	5.459E-04	7.276E-04	6.484E-04	6.729E+02
Te123m	8.572E-10	1.819E-09	1.421E-10	1.309E-11	2.984E-10	6.345E-10	4.401E-10	9.894E+08
Te125m	2.842E-12	6.036E-12	4.685E-13	4.314E-14	9.892E-13	2.105E-12	1.459E-12	2.982E+11
Te127	2.061E-06	3.225E-06	1.203E-06	1.171E-07	7.992E-07	1.255E-06	1.045E-06	5.582E+05
Te127m	2.162E-07	3.225E-07	1.567E-07	1.575E-08	8.845E-08	1.302E-07	1.114E-07	5.582E+06
Te129	4.045E-04	5.585E-04	4.028E-04	4.377E-05	1.835E-04	2.479E-04	2.192E-04	2.056E+03
Te129m	1.421E-04	2.045E-04	1.181E-04	1.227E-05	5.978E-05	8.620E-05	7.432E-05	7.337E+03
Th227	1.640E-04	1.809E-04	3.346E-04	4.278E-05	7.454E-05	8.391E-05	8.333E-05	2.104E+03
Th228	1.548E-04	1.682E-04	3.237E-04	4.150E-05	7.069E-05	7.861E-05	7.858E-05	2.169E+03
Th229	1.075E-04	1.169E-04	2.241E-04	2.876E-05	4.898E-05	5.455E-05	5.446E-05	3.129E+03
Th230	9.363E-05	1.017E-04	1.956E-04	2.511E-05	4.269E-05	4.752E-05	4.745E-05	3.584E+03
Th231	1.824E-09	3.094E-09	7.849E-10	7.446E-11	6.744E-10	1.158E-09	9.254E-10	5.819E+08
Th232	4.428E-05	4.824E-05	9.293E-05	1.198E-05	2.031E-05	2.269E-05	2.255E-05	7.515E+03
Th234	2.592E-12	5.505E-12	4.273E-13	3.934E-14	9.021E-13	1.919E-12	1.331E-12	3.270E+11
Tl206	4.833E-07	6.824E-07	4.242E-07	4.441E-08	2.063E-07	2.947E-07	2.522E-07	2.027E+06
Tl207	3.963E-05	5.625E-05	3.445E-05	3.610E-06	1.691E-05	2.416E-05	2.072E-05	2.493E+04
Tl208	1.409E+00	1.754E+00	2.036E+00	2.551E-01	7.707E-01	9.526E-01	8.510E-01	3.528E-01
Tl209	2.821E-01	3.656E-01	3.491E-01	4.076E-02	1.415E-01	1.802E-01	1.618E-01	2.208E+00
Tm168	1.097E-02	1.540E-02	9.945E-03	1.054E-03	4.759E-03	6.719E-03	5.773E-03	8.535E+01
Tm170	1.071E-06	1.614E-06	7.461E-07	7.493E-08	4.304E-07	6.517E-07	5.495E-07	1.115E+06
Tm171	7.772E-21	1.651E-20	1.281E-21	1.180E-22	2.705E-21	5.756E-21	3.990E-21	1.090E+20
U232	1.443E-04	1.567E-04	3.016E-04	3.867E-05	6.586E-05	7.325E-05	7.321E-05	2.327E+03
U233	1.035E-04	1.124E-04	2.161E-04	2.774E-05	4.718E-05	5.251E-05	5.244E-05	3.244E+03
U234	1.004E-04	1.091E-04	2.097E-04	2.692E-05	4.578E-05	5.095E-05	5.088E-05	3.343E+03
U235	6.624E-05	7.210E-05	1.384E-04	1.778E-05	3.025E-05	3.373E-05	3.362E-05	5.061E+03
U236	8.989E-05	9.777E-05	1.884E-04	2.420E-05	4.118E-05	4.586E-05	4.573E-05	3.719E+03
U237	6.818E-07	1.156E-06	2.932E-07	2.781E-08	2.520E-07	4.327E-07	3.458E-07	1.557E+06
U238	7.916E-03	8.642E-03	1.689E-02	2.167E-03	3.716E-03	4.142E-03	4.110E-03	4.153E+01
U239	9.689E-05	1.368E-04	8.554E-05	8.988E-06	4.146E-05	5.899E-05	5.071E-05	1.001E+04
U240	1.235E-09	2.121E-09	5.073E-10	4.801E-11	4.542E-10	7.895E-10	6.265E-10	8.487E+08
W181	1.158E-12	2.460E-12	1.909E-13	1.758E-14	4.031E-13	8.577E-13	5.945E-13	7.318E+11
W185	3.681E-09	6.085E-09	1.737E-09	1.658E-10	1.377E-09	2.305E-09	1.867E-09	2.958E+08
W188	8.418E-09	1.494E-08	3.016E-09	2.829E-10	3.052E-09	5.481E-09	4.269E-09	1.205E+08
Xe127	5.931E-06	9.801E-06	2.805E-06	2.680E-07	2.221E-06	3.714E-06	3.011E-06	1.837E+05
Xe131m	1.971E-11	4.186E-11	3.249E-12	2.992E-13	6.860E-12	1.460E-11	1.012E-11	4.300E+10
Y88	4.333E-01	5.546E-01	5.541E-01	6.575E-02	2.200E-01	2.795E-01	2.508E-01	1.369E+00

Table 7.5-8 - [redacted] SIA Unit Dose Rates and Maximum Activity Results, Nonexclusive Use (6 Pages)

Isotope	NCT Unit Dose Rates (mSv/hr/TBq)				HAC Unit Dose Rates (mSv/hr/TBq)			Activity Limit (TBq)
	Package Surface			1-Meter	1-Meter			
	Top	Bottom	Side	Side[1]	Top	Bottom	Side	
Y89m	1.727E-02	2.398E-02	1.612E-02	1.715E-03	7.496E-03	1.052E-02	9.114E-03	5.248E+01
Y90	3.455E-04	4.686E-04	3.658E-04	4.076E-05	1.605E-04	2.154E-04	1.895E-04	2.208E+03
Y90m	1.812E-04	2.828E-04	1.069E-04	1.042E-05	7.039E-05	1.102E-04	9.190E-05	6.365E+03
Y91	2.404E-04	3.242E-04	2.545E-04	2.821E-05	1.130E-04	1.507E-04	1.317E-04	3.190E+03
Zn65	2.286E-02	3.125E-02	2.362E-02	2.582E-03	1.052E-02	1.401E-02	1.249E-02	3.485E+01
Zr88	2.749E-05	4.501E-05	1.326E-05	1.265E-06	1.031E-05	1.712E-05	1.395E-05	3.999E+04
Zr90m	8.706E-01	1.102E+00	1.201E+00	1.472E-01	4.633E-01	5.811E-01	5.123E-01	6.116E-01
Zr95	4.761E-03	6.863E-03	3.873E-03	3.991E-04	1.988E-03	2.879E-03	2.453E-03	2.255E+02

Notes:

(3) The dose rate at 1-meter from the side of the package bounds the dose rate at 1-meter from the top and bottom of the package based on inspection of the package surface dose rates. Therefore, 1-meter dose rates on the ends of the package are not reported.

Attachment 7.5-2
Example CCV Pre-Shipment Inerting Procedure

The following procedure is an example of an acceptable pre-shipment inerting procedure for the CCV, which is only required when shipping TRU waste contents with a total decay heat load exceeding 50 watts or when shipping irradiated fuel waste. The following example procedure is based on process that has been proven effective for TRU waste contents through testing [7.2]. Alternate procedures that are proven effective in reducing the oxygen gas trapped inside the waste container confinement boundaries to 1% or less are also acceptable.

1. Connect the inerting apparatus to the CCV lid quick connect fitting as shown in Figure 7.5-1.

2. Ensure that the Purge and Vacuum Valves are closed, the Helium Cylinder has adequate pressure, the vacuum pump is running, and the Pressure Regulator is set to 25 psig outlet pressure.

   Note: Completion of the pump-down operation is indicated when the noise-level of the vacuum pump suddenly decreases because it is pumping low volumes of gas.

3. Open the Vacuum Valve and monitor the pressure reading on the Pressure Gauge until it falls below 0.1 psia (5 torr), then close the Vacuum Valve.

   Note: An increase in pressure is an indication trapped gas in the confinement volumes of the contents is escaping to the CCV cavity.

4. Wait at least 10 minutes for potentially trapped gas to escape through the vent mechanisms of the waste container confinement boundaries (e.g., filters, vents, or permeable membrane) into the CCV cavity.

   Note: The second purge-evacuation cycle (Steps 5 through 8) dilutes any remaining trapped gas with helium gas to reduce the concentration of oxygen gas.

5. Open the Purge Valve and backfill the CCV cavity with 1 atm helium gas.

   Note: A decrease in the pressure indicates the backfill gas in the CCV is penetrating secondary container and confinement volumes. No decrease in

pressure indicates the backfill gas has fully penetrated all confinement volumes of the contents.

6. Close the Purge Valve and monitor the pressure reading on the Pressure Gauge for at least 10 minutes to allow the helium fill gas to penetrate the waste container confinement boundaries.

7. Open the Vacuum Valve and monitor the pressure reading on the Pressure Gauge until it falls below 0.1 psia (5 torr), then close the Vacuum Valve.

   Note: A detectable increase in pressure is an indication there is still trapped gas in the confinement volumes of the contents that is escaping to the CCV cavity. No detectable increase in pressure over a period of 15 minutes indicates all trapped gas has been evacuated from all confinement volumes of the contents.

8. Monitor the Pressure Gauge reading for at least 15 minutes to ensure that there is no detectable increase in the pressure reading.

9. If an increase in the pressure reading is detected, repeat Steps 5 through 8.

10. Open the Purge Valve and backfill the CCV cavity with 1 atm Helium.

11. Wait at least 10 minutes for the helium fill gas to penetrate the waste container confinement boundaries.

    Note: A decrease in the pressure indicates the backfill gas in the CCV is still penetrating the secondary container and confinement volumes. No decrease in pressure indicates the backfill gas has fully penetrated all confinement volumes of the contents.

12. If the pressure in the CCV cavity falls below 1 atm the during soak time, open the Purge Valve and backfill the CCV cavity with 1 atm Helium. Repeat Steps 11 and 12 until a stable backfill pressure of 1 atm is reached.

13. Disconnect the inerting apparatus from the CCV lid quick connect fitting.

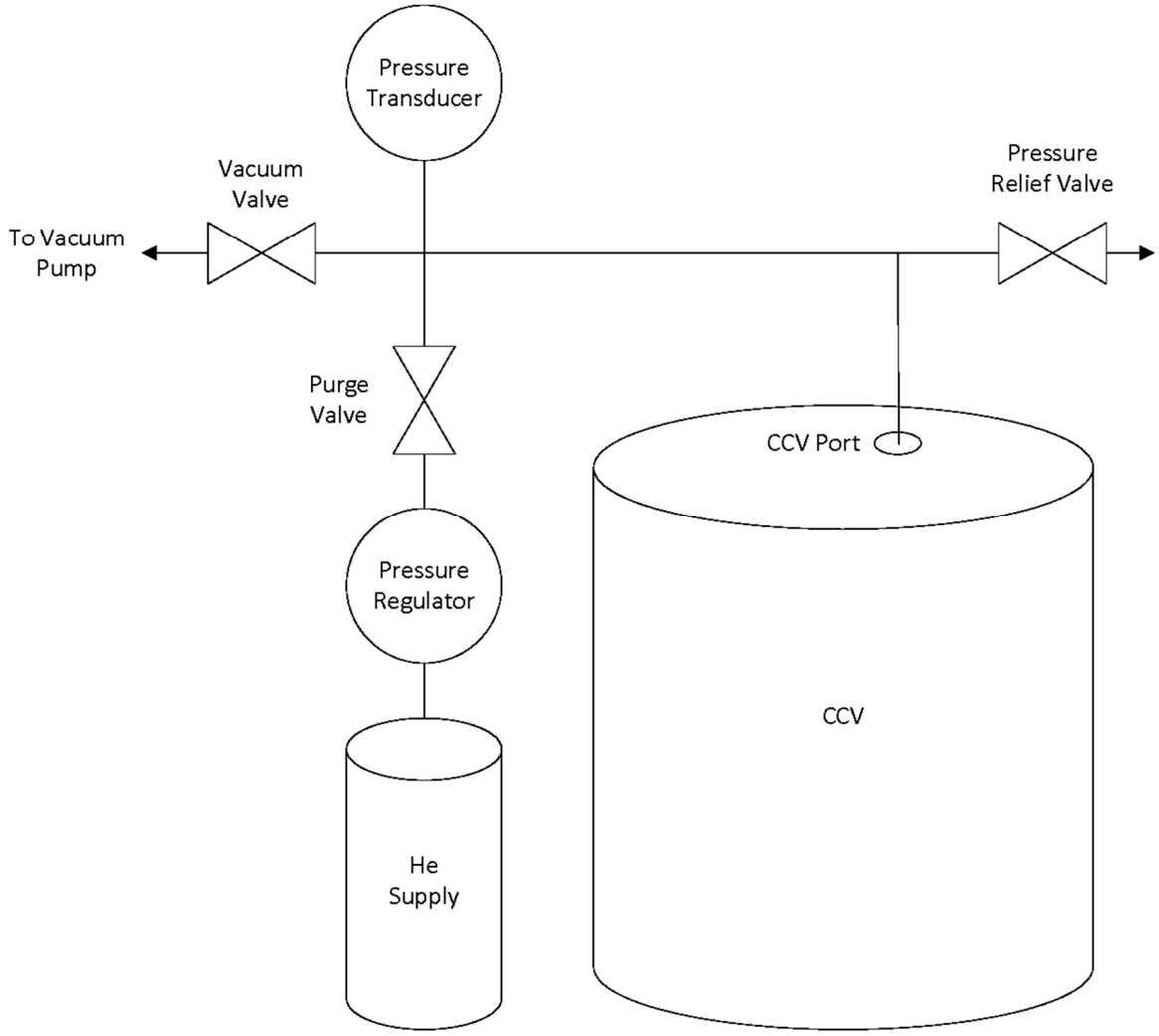


Figure 7.5-1 Pre-Shipment Inerting Apparatus Schematic

Attachment 7.5-3
Procedure for Determination of Flammable Gas Concentration and Shipping Time

The procedure for package users to determine the flammable gas concentration in any containment volume of authorized contents using the method discussed in Section 4.5.4 is outlined below. Example hydrogen gas accumulation calculations using this procedure for hypothetical contents are provided in Section 4.5.4.4.

Determination of waste forms/quantities may be made by the user based on process/historical knowledge, measurement/sampling, radiography, or visual inspection. Certain parameters necessary for the hydrogen gas accumulation calculations are dependent on the packaging configuration. Each of these will have a different CCV free volume and bounding NCT temperature based on the packaging configuration and contents. The free volume within the CCV cavity for the three packaging configurations shown on Drawing 70000.14-501 in Appendix 1.3.3, accounting for internal support structures (e.g., SIA and/or CCV bottom support plate) but excluding the waste contents in secondary containers are provided in Table 7.5-1. The temperature of the contents based on its total decay heat load is determined in accordance with Figure 7.5-2.

The procedural steps for the user to determine the flammable gas concentration in any containment volume of authorized contents and the resulting permissible transport time (i.e., shipping window) are as follows:

1. **Determine the volumes of the outermost and innermost confinement regions.**[2] Any uncertainty in a region's volume shall be treated in a conservative manner, i.e., always assume the minimum available volume based on content data.

   a. The outermost region is always the CCV cavity, the volume of which is reduced by the space taken up by any internal support structures (e.g., SIA and shoring/dunnage) and the volume of the secondary container. The starting free volume for the given configuration is provided in Table 7.5-1, which lists the free volume as the volume of the CCV cavity minus the space taken up by the internal support structures included in the respective configuration. This volume shall be reduced by the volume of the content's secondary container (e.g., liner, 55-gallon drum, etc.) and any additional shoring between the CCV and the secondary container that is not shown on the general arrangement drawings.

[2] For the hydrogen gas calculation method, only the innermost and outermost volumes are considered. Any intermediate volumes are neglected and only the reduction in release rate from the additional boundaries is considered. For example, for a 55-gallon drum nested within a 110-gallon drum, the volume between the two drums is not considered, only the combined resistance to gas flow through the two filters on the drums.

b. The innermost region could be the secondary container in the form of a 55-gallon (208 L) drum, 110-gallon (418 L) drum, or other secondary container(s). The innermost containment volume could also be the innermost nested volume inside the secondary container (e.g., vented cans or bags). The volume inside the innermost region that is taken up by its contents must be accounted for (i.e., only free volume should be considered).

2. **Determine bounding G-values of contents (See Section 4.5.4.1).** The maximum G-value of all hydrogenous materials in the contents should be selected to ensure a bounding calculation.

   a. Account for content radiation type (Optional). The proportions of the α and β vs. γ radiation of the contents may be used to determine a lower "dose-dependent" G-value, if the contents meet the 0.012 watt-year absorbed dose criteria.

   b. Account for content temperature (Required). The G-value must be adjusted based on the difference between the source data temperature (typically room temperature) and the bounding NCT temperature of each cavity gas (i.e., whether the cavity is filled with helium or air). The temperature of the cavity gas and contents is determined as a function of the fill gas and total decay heat load based on Figure 7.5-2.

   c. Calculate the Flammable Gas Generation Rate (FGGR) based on the temperature-adjusted G-value and content decay heat.

3. **Determine release rates for each confinement region (See Section 4.5.4.2).** Each confinement region (except the CCV) must have some venting mechanism (e.g., a filter) to allow the flow of gas out of the volume container. The release rate (RR) of each venting mechanism shall be determined based on either available product data, published industry accepted data, or test data.

   a. Account for content temperature (Required). The release rate (RR_i) of each confinement region should be temperature-adjusted based on the difference between the temperature of the source data (room temperature if not otherwise stated) and the content temperature.

   b. Determine the effective release rate (T_{eff}). For one boundary, T_{eff} is equal to the release rate (RR) of the vent on the secondary container. If there are nested containers (e.g., a sealed bag inside of a 55-gallon drum) T_{eff} is the effective resistance of the combined release rates of the individual layers calculated in accordance with Section 4.5.4.2.

4. **Determine permissible transport time (See Section 4.5.4.3).** Using the equation provided, determine the time, t, that it would take to reach a hydrogen volume fraction, $X_i(t)$, equal to the set limit for the given contents. If this time is less than 1 year, the permissible transport time is set as ½ of the determined time, t. For most contents, two separate cases must be considered to account for the competing effects of flammable gas generation rate and release rate at the maximum and minimum temperatures: the maximum temperature of the contents for NCT heat (from Figure 7.5-2) and the minimum temperature of the contents for NCT cold (i.e., -40°C). Typically, the hot case produces shorter transport times because the temperature increase effect on flammable gas generation rate is greater than the temperature decrease effect on the release rate. However, this is not the case for a content material like water, for which the flammable gas generation rate is not temperature dependent (see NUREG/CR-6673, Section 2.4.2). In this case, the cold case will always be bounding because temperature only affects the release rate.

Table 7.5-9 - CCV Free Volume and Fill Gas Temperatures

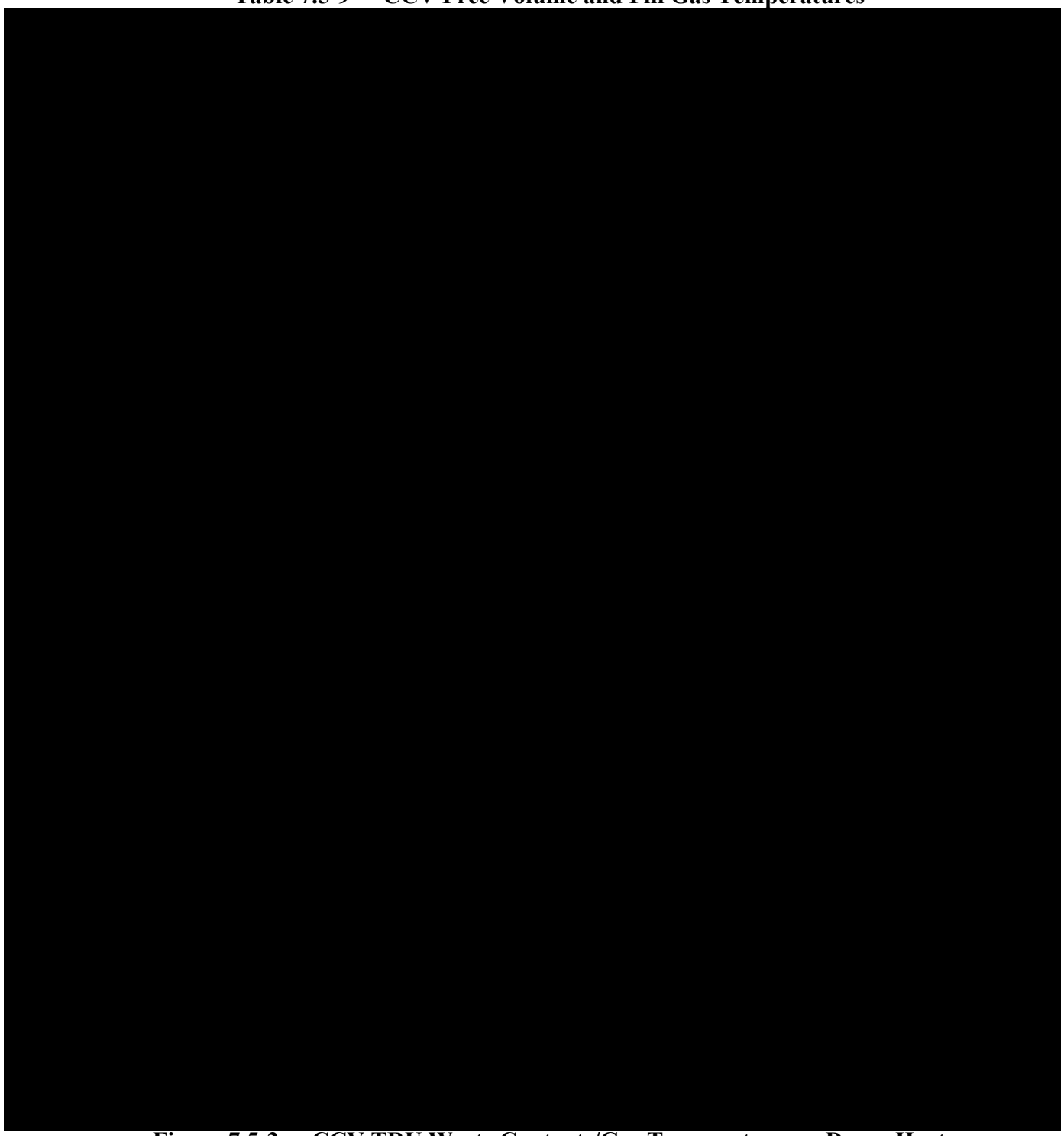


Figure 7.5-2 - CCV TRU Waste Contents/Gas Temperature vs. Decay Heat

Chapter 8
Acceptance Tests and Maintenance Program

Table of Contents

8 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM 8-1

8.1 Acceptance Tests 8.1-1
8.1.1 Visual Inspections and Measurements 8.1-1
8.1.2 Weld Examinations 8.1-1
8.1.3 Structural and Pressure Tests 8.1-1
8.1.4 Fabrication Leakage Rate Tests 8.1-2
8.1.5 Component and Material Tests 8.1-2
8.1.6 Shielding Tests 8.1-5
8.1.7 Thermal Tests 8.1-5
8.1.8 Miscellaneous Tests 8.1-5

8.2 Maintenance Program 8.2-1
8.2.1 Structural and Pressure Tests 8.2-1
8.2.2 Leakage Rate Tests 8.2-1
8.2.3 Component and Material Tests 8.2-3
8.2.4 Thermal Test 8.2-6
8.2.5 Miscellaneous Tests 8.2-6

8.3 Appendix 8.3-1
8.3.1 References 8.3-1

List of Tables

Table 8.1-1 Foam Static Crush Strength Acceptance Criteria 8.1-6
Table 8.2-1 Summary of Packaging Maintenance Requirements 8.2-8

8 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This chapter presents the acceptance tests and maintenance program for the OPTIMUS®-H packaging. These activities assure that the packaging meets the requirements of 10 CFR 71, Subpart G.

This page intentionally left blank.

8.1 Acceptance Tests

This section describes the tests to be performed before the first use of each packaging. The acceptance tests confirm that each packaging is fabricated in accordance with the general arrangement drawings in the Certificate of Compliance.

8.1.1 Visual Inspections and Measurements

Packaging components shall receive visual and mechanical inspections to verify the packaging has been fabricated and assembled in accordance with the general arrangement drawings in Section 1.3. The dimensions, tolerances, and surface finishes shown on the drawings shall be verified by measurement on each packaging. Nonconforming components shall be reworked or replaced.

8.1.2 Weld Examinations

All packaging welds shall be examined to the requirements of the general arrangement drawings in Section 1.3. Nonconforming components shall be reworked or rejected.

8.1.3 Structural and Pressure Tests

8.1.3.1 Lifting Attachment Load Test

The packaging is designed to be lifted by the two trunnions located on the OSV body casting or by two diametrically-opposed tiedown lugs located on the OSV body casting. The maximum service load for the lifting attachments is a vertical load of 30,000 pounds (133 kN), or 15,000 pounds (67 kN) per trunnion or tiedown lug. Prior to the initial use of the OSV, the trunnions and both sets of diametrically-opposed tiedown lugs shall be subjected to a vertical test load equal to 300% of the maximum service load, equal to 90,000 pounds (400 kN), or 45,000 pounds (200 kN) per trunnion or tiedown lug. The test load shall be sustained for a period of 10 minutes or more. Following the load test, the critical areas of the OSV casting, on and around the trunnions and tiedown lugs, shall be visually examined for indications of plastic deformation and/or cracking and examined for surface discontinuities by means of magnetic particle (MT) examination in accordance with ASTM E709 [8.4]. Indications of distortion and/or cracking shall be recorded on a nonconformance report and dispositioned prior to final acceptance in accordance with the cognizant quality assurance program.

8.1.3.2 Hydrostatic Pressure Testing of the Containment Boundary

In accordance with the requirements of 10 CFR 71.85(b), each CCV assembly shall be pressure tested to 150% of the packaging design pressure to verify the capability of the containment

system to maintain its structural integrity at the test pressure. The design pressure of the CCV assembly is 100 psi (690 kPa) gauge. Therefore, each CCV assembly shall be pressure tested at 150 psi (1,034 kPa) gauge.

In accordance with the requirements of NB-6223 [8.1], the test pressure will be maintained for a minimum of 10 minutes prior to initiation of the examination for leakage. Following the application of the test pressure, the CCV assembly shall be visually examined for leakage in accordance with NB-6224 [8.1]. In addition, the welded connections of the CCV assembly shall be examined for cracking and/or distortion using visual and liquid penetrant (PT) methods in accordance with NB-5000 [8.1]. The acceptance criteria for the pressure test are no unacceptable leakage or distortion of the containment boundary. A nonconforming CCV assembly shall be reworked or rejected.

8.1.4 Fabrication Leakage Rate Tests

The CCV assembly (i.e., the packaging containment boundary) shall be leakage rate tested in accordance with ANSI N14.5 [8.6] to an acceptance criterion of 1×10^{-7} ref-cm^3/sec (2×10^{-7} cm^3/sec helium). Leakage rate testing shall be performed using helium as the tracer gas and a suitable helium leak detector with a minimum sensitivity of 5×10^{-8} ref-cm^3/sec (1×10^{-7} cm^3/sec helium). Calibrated standard leaks shall have current calibration traceable to NIST. A CCV assembly that does not meet the acceptance criteria shall be reworked, replaced, or repaired, as required, and retested prior to acceptance.

Separate acceptance leakage rate tests may be performed for the CCV body assembly, CCV lid assembly, and/or vent port plug assembly containment boundaries using test heads or manifolds, as appropriate. Furthermore, the acceptance leakage rate test of the packaging containment system may be performed using temporary seals, which must be replaced prior to final acceptance. All containment O-rings that are not used for the acceptance leakage rate test shall be subjected to the maintenance leakage rate testing described in Section 8.2.2.1 prior to their initial use.

8.1.5 Component and Material Tests

8.1.5.1 Elastomeric O-ring Seals

Containment O-rings will be made from the Fluorocarbon-Viton compound specified on the General Arrangement Drawings that has been qualified based on testing to verify material composition, physical properties (hardness, tensile strength, elongation, and specific gravity), low temperature properties, and compression set at high temperature. In addition, each O-ring will be subjected to dimensional acceptance testing.

8.1.5.2 Ductile Cast Iron

Ductile cast iron (DCI) material used to construct the OSV body and lid is tested for chemical composition, mechanical properties, microstructure properties, and fracture toughness, as discussed in this section. [redacted] DCI not meeting the acceptance criteria shall be rejected.

Chemical Composition and Mechanical Properties

[redacted]

Microstructure Properties

[redacted]

Fracture Toughness

[redacted]

8.1.5.3 Impact Limiter Foam

Each batch of closed-cell polyurethane foam used to construct the foam segments of the upper and lower impact limiter assemblies shall be tested for the following attributes. Foam not meeting the acceptance criteria shall be rejected.

Leachable Chlorides

[redacted]

Average Density

[redacted]

[redacted]

Static Crush Strength

[redacted]

Flame Retardancy

[redacted]

Intumescence

[redacted]

[redacted]

8.1.6 Shielding Tests

The packaging does not require shielding acceptance testing because the shielding component are made from solid stainless steel and DCI. The packaging does not in include any special shielding features, such as a poured lead gamma shield, and the material properties used for the shielding evaluation of the package are sufficiently conservative.

[redacted]

8.1.7 Thermal Tests

The packaging does not require thermal acceptance testing because it does not include any special thermal features and the material properties used for the thermal evaluation of the package are sufficiently conservative.

8.1.8 Miscellaneous Tests

Not Applicable.

Table 8.1-1 - Foam Static Crush Strength Acceptance Criteria

8.2 Maintenance Program

The maintenance program includes periodic inspections, tests, and maintenance activities designed to ensure continued performance of the packaging. This section describes the periodic testing, inspection, and replacement schedules, as well as the criteria for replacement and repair of components and subsystems on an as-needed basis. The maintenance requirements are summarized in Table 8.2-1.

8.2.1 Structural and Pressure Tests

The packaging does not require any routine structural or pressure tests. This includes the replacement of CCV closure bolts or threaded inserts which are exempted from the pressure test per NB-6111 [8.1]. The replacement requirements for threaded fasteners or inserts are presented in Section 8.2.3.

8.2.2 Leakage Rate Tests

8.2.2.1 Periodic and Maintenance Leakage Rate Testing

Periodic leakage rate testing is performed in accordance with Section 7.5 of ANSI N14.5 [8.6] to confirm that the containment capabilities of the CCV assembly have not deteriorated over an extended period of use. A periodic leakage rate test is required to be performed on every containment seal of the packaging within the 12-month period prior to every shipment but need not be performed for packages that are out-of-service (e.g., placed into temporary storage). As discussed in Section 8.2.3.1, all packaging O-rings and fastener seals are required to be replaced within the 12-month period prior to any shipment and, therefore, the maintenance leakage rate testing of the replaced containment seals also satisfies the requirement for periodic leakage rate testing.

Maintenance leakage rate testing of all packaging containment seals are performed in accordance with Section 7.4 of ANSI N14.5 [8.6] prior to returning the package to service following maintenance, repair, or replacement of any components of the containment system to confirm that the CCV assembly is not degraded. As discussed in Sections 8.2.3.1 and 8.2.3.2, maintenance leakage rate testing is required after replacement of any packaging containment system O-ring or fastener seal and after repair of any containment sealing surface. Maintenance leakage rate testing need only be performed on the affected seal or sealing surface of the containment system.

Leak-tight acceptance criteria of 1×10^{-7} ref-cm^3/sec (2×10^{-7} cm^3/sec helium) shall be used for the periodic and maintenance leakage rate tests. Periodic and maintenance leakage rate testing shall be performed in accordance with ANSI N14.5 [8.6] using helium as the tracer gas and a suitable

helium leak detector with a sensitivity of at least 5×10^{-8} ref-cm^3/sec (1×10^{-7} cm^3/sec helium). Calibrated standard leaks shall have current calibration traceable to NIST.

A CCV assembly that does not satisfy the periodic and maintenance leakage rate test acceptance criteria shall be reworked, replaced, or repaired, as required, and retested prior to returning the packaging to service. Periodic and maintenance leakage rate test results and any associated rework, replacement, or repairs shall be documented in a packaging maintenance log.

8.2.2.2 Pre-shipment Leakage Rate Testing

Pre-shipment leakage rate testing of the CCV lid containment seal and the CCV vent port containment seal[1] of the loaded packaging is required before each shipment of a loaded package to verify that the containment system is properly assembled for shipment. The components that require pre-shipment leakage rate tests include the CCV lid and port cover containment O-ring seals. If a containment seal requires replacement during loading operations, maintenance leakage rate testing of the closure with a new containment seal is required prior to shipment in accordance with the requirements of Section 8.2.2.1. In this case, the maintenance leakage rate test of the closure with the new containment seal satisfies the requirement for pre-shipment leakage rate testing.

Pre-shipment leakage rate tests shall be performed using the Gas Pressure Drop or Gas Pressure Rise methods described in Sections A.5.1 and A.5.2 of ANSI N14.5 [8.6]. The acceptance criterion for the pre-shipment leakage rate test is no detectable leakage when tested to a sensitivity of $1x10^{-3}$ ref-cm^3/sec. The pressure gauge used to perform the pre-shipment leakage rate test shall have an NIST traceable calibration and be accurate to within 1% or less of its full scale.

The procedure for the pre-shipment leakage rate test shall be qualified based on the guidance provided in Article 1, T-150(d) of the ASME Code, Section V, Subsection A [8.7] using a calibrated leak standard for the T-150(d)(2) test specimen to demonstrate that it will reliably produce a test sensitivity of $1x10^{-3}$ ref-cm^3/sec or better. Alternatively, a leakage rate test procedure that relies upon detection of a system calibrated leak standard in each performance of the test does not require a separate procedure qualification, as it is inherently qualified each time it is performed.

Any containment seal that does not satisfy the pre-shipment leakage rate test acceptance criteria shall be inspected, cleaned (if needed), reassembled, and retested prior to shipment. Any

[1] Pre-shipment leakage rate testing of the CCV vent port containment seal is required before every Type B shipment, even if the CCV vent port cover was not removed during the loading process.

containment seal that does not satisfy the pre-shipment leakage rate test acceptance criteria after repeated attempts, may require replacement of the O-ring seal or fastener seal or repair of the sealing surface. As discussed in Sections 8.2.3.1 and 8.2.3.2, a maintenance leakage rate test is required for all new/replaced containment O-ring and fastener seals and any repaired sealing surfaces for containment O-rings and fastener seals. Replacement of non-containment O-rings (i.e., test O-rings and the vent/drain port cap O-rings) and repair of sealing surfaces for non-containment O-rings does not require a maintenance leakage rate test.

8.2.3 Component and Material Tests

The following sections describe the periodic tests and replacement schedules for packaging components used to ensure continued performance of the packaging. Additional maintenance may be required on an as-needed basis when wear or damage is noted during routine operations. When as-needed maintenance is performed, the associated repair, replacement, and record keeping activities shall follow the maintenance program requirements for the corresponding periodic maintenance activity.

8.2.3.1 O-ring Seals

Prior to each shipment, all accessible packaging O-ring seals and fastener seals are visually inspected for any damage or defects (e.g., cracks, tears, cuts, or discontinuities) that may prevent them from sealing properly when the package is assembled. If the CCV port cover is not removed during the loading operations, the associated O-ring seals are not subjected to visual inspection. However, a pre-shipment leakage rate test is required for the CCV lid and port cover containment O-ring and fastener seals prior to each use to verify the package is properly assembled for shipment, as discussed in Section 8.2.2.2. Damaged or defective O-ring seals shall be replaced with new O-ring seals that meet the requirements on the general arrangement drawing in Section 1.3 and the requirements of Section 8.1.5.1, as applicable. A maintenance leakage rate test is required for any replaced CCV lid or port cover O-ring, per Section 8.2.2.1. The CCV lid and port cover test O-rings and the CCV test port O-rings do not provide containment, and therefore, do not require a pre-shipment leakage rate test or maintenance leakage test when replaced. The O-ring seal inspection results and any necessary O-ring seal replacements and required leakage rate tests shall be documented in a packaging maintenance log.

All packaging O-ring seals shall be replaced with new O-ring seals that meet the requirements shown on the general arrangement drawing in Section 1.3 and the requirements of Section 8.1.5.1, as applicable, within the 12-month period prior to any shipment. A maintenance leakage rate test is required for all CCV containment O-ring seals that are replaced, per Section 8.2.2.1.

Test O-ring seals that are replaced do not require a maintenance leakage rate test, however, they may be used to perform the maintenance leakage rate test of the associated containment O-ring. The CCV test port O ring seals, which only serve as dust/weather seals, do not require any leakage rate testing when replaced. The periodic replacement of O-ring or fastener seal and the required leakage rate tests shall be documented in a packaging maintenance log.

New O-ring and fastener seals shall be coated with vacuum grease or lightweight lubricant prior to installation to aid in installation and minimize deterioration or cracking of the elastomer during usage and the potential for tearing if removed from the dovetail groove is necessary for inspection. The exposed surfaces of installed O-ring and fastener seals that do not require replacement shall also be coated prior to assembling the packaging to minimize deterioration or cracking of the seal during use. Remove excess coating from the O-ring and fastener seals prior to assembling the packaging.

8.2.3.2 Sealing Surfaces

Prior to each shipment and during period maintenance (which is required within the 12-month period prior to any shipment) the sealing surfaces for all O-rings and fastener seals shall be cleaned and visually inspected for wear and/or damage (e.g., scratches, gouges, nicks, cracks, etc.) that may prevent the containment O-rings and fastener seals from sealing properly. Worn or damaged sealing surfaces may be repaired by machining or with a suitable polishing agent to restore the surface finish as required for proper sealing. A maintenance leakage rate test is required for all repaired sealing surfaces for containment O-rings, per Section 8.2.2.1. Repaired sealing surfaces for non-containment O-rings (i.e., test O-rings and the vent/drain port cap O-rings) do not require a maintenance leakage rate test. The inspection results and any necessary sealing surface repairs and leakage rate tests shall be documented in a packaging maintenance log.

8.2.3.3 Threaded Fasteners

Prior to each shipment, all packaging threaded fasteners (e.g., impact limiter swing bolts and nuts, CCV and OSV lid bolts, CCV vent port plug bolts, CCV test port plugs, and OSV drain port plug) removed during package loading operations shall be visually inspected for excessive wear and/or damage. However, fasteners that are not removed during the unloading and loading operations do not require visual inspection prior to use. In addition, all packaging threaded fasteners, including those not removed during loading or unloading operations, shall be visually inspected for excessive wear and/or damage within the 12-month period prior to any shipment.

Fasteners that have minor damage or wear may be refurbished by chasing the threads. Barbs may also be removed, taking care not to cause further thread damage. Minor surface corrosion

on fasteners may be removed by polishing with an emery cloth or other fine abrasives. Fasteners that show visible signs of excessive wear or significant corrosion or damage shall be replaced with new fasteners that meet the requirements on the general arrangement drawing in Section 1.3. All repaired or replaced threaded fasteners shall be functionally tested prior to use to verify proper fit-up with the mating component of the packaging. Inspection results and any necessary fastener repairs and replacements shall be documented in a packaging maintenance log.

Tapped holes for threaded fasteners do not require visual inspection. However, all fastener holes with threaded inserts shall be visually inspected within the 12-month period prior to any shipment to verify that the threaded inserts are not displaced or damaged. Tapped holes that do not fit-up properly with the mating fastener may be refurbished by chasing the threads or repaired as necessary using threaded inserts per the general arrangement drawing in Section 1.3.

Displaced threaded inserts shall be re-positioned and secured in the hole or replaced with a new threaded insert, as necessary. Damaged threaded inserts shall be replaced with new threaded inserts that meet the applicable requirements on the general arrangement drawing in Section 1.3. The associated assemblies shall be functionally tested to confirm proper fit and function of the threaded connections. The inspection results and any necessary thread insert repairs and replacements shall be documented in a packaging maintenance log.

8.2.3.4 Exposed Packaging Surfaces

Prior to each shipment, the exterior of the packaging, including the impact limiters and OSV assembly, is visually inspected to verify its physical condition is unimpaired. Superficial defects on the exterior of the packaging, such as marks, scratches, or dents, do not require repair. However, any significant damage to the packaging exterior, such as holes in the steel skins on the impact limiters, shall be repaired prior to shipment. The inspection results and any necessary repairs to the exterior of the packaging shall be documented in a packaging maintenance log.

All exposed interior and exterior surfaces of the top and bottom impact limiter assemblies, OSV body and lid assemblies, OSV drain port plug, CCV body and lid assemblies, CCV vent and test port plugs, and SIA body and lid assemblies shall be visually inspected within the 12-month period prior to any shipment for damage or degradation that could impair the physical condition of the packaging. Superficial defects, such as minor surface corrosion, scratches, blemishes, and adhered material/particles, may be removed by polishing the packaging surfaces with emery cloth or other fine abrasives. Significant damage of the packaging exterior shall be repaired to restore the packaging to the applicable requirements on the general arrangement drawing in Section 1.3 or the damaged components may be replaced. Replacement components shall satisfy the applicable requirements on the general arrangement drawing in Section 1.3 and the

applicable acceptance tests described in Section 8.1. The inspection results and any necessary repairs to the packaging surfaces or replacement of packaging components shall be documented in a packaging maintenance log.

Painted surfaces, identification markings, and match marks used for closure orientation shall be visually inspected within the 12-month period prior to any shipment, to ensure that painted surfaces are in good condition, identification markings are legible, and that match marks used for closure orientation remain legible and are easy to identify.

Lifting attachments shall be inspected within the 12-month period prior to any shipment to verify that there is no evident permanent deformation and no obvious damage or defects. Damaged or defective lifting attachments shall be repaired or replaced in accordance with the applicable requirements on the general arrangement drawing in Section 1.3 and the applicable acceptance tests described in Section 8.1.

8.2.4 Thermal Test

No periodic or routine thermal testing are required to be performed on the packaging.

8.2.5 Miscellaneous Tests

The following subsections discuss the requirements following replacement of packaging components. These requirements apply to newly manufactured components (spares) or substituted components from other OPTIMUS®-H packagings. For configuration management, the OSV body is the host component because it bears the packaging nameplate. Other components may be substituted following these procedures.

8.2.5.1 OSV Lid Replacement or Repair

If an OSV lid must be replaced, the replacement lid shall be assembled with the mating OSV body to assure proper fit-up of the OSV components. The replacement shall be noted in the packaging's maintenance log along with the test and inspection results.

8.2.5.2 Impact Limiter Assembly Replacement or Repair

If an impact limiter assembly must be replaced, the replacement impact limiter assembly shall be assembled with the mating end of the OSV assembly to assure proper fit-up. The replacement shall be noted in the packaging's maintenance log along with the test and inspection results.

8.2.5.3 CCV Assembly Replacement or Repair

If a CCV body, lid, or port cover must be replaced, the replaced CCV component shall be assembled with the mating CCV component to assure proper fit-up. A maintenance leakage rate

test of the containment O-ring seal affected by the replacement shall be performed in accordance with Section 8.2.2.1. The replacement shall be noted in the packaging's maintenance log along with the test and inspection results.

If an entire CCV assembly must be replaced, the replacement shall be noted in the packaging's maintenance log. The replacement CCV assembly must either be a unit currently in service, or another unit manufactured or refurbished to the requirements shown in the general arrangement drawings in Section 1.3.

8.2.5.4 SIA Assembly Replacement or Repair

If an SIA lid must be replaced, the replaced SIA lid shall be assembled with the mating SIA body to assure proper fit-up. The replacement shall be noted in the packaging's maintenance log along with the test and inspection results.

If an entire SIA assembly must be replaced, the replacement shall be noted in the packaging's maintenance log. The replacement SIA assembly must either be a unit currently in service, or another unit manufactured or refurbished to the requirements shown in the general arrangement drawings in Section 1.3.

Table 8.2-1 - Summary of Packaging Maintenance Requirements

Item	Reference SAR Section	Inspection/Test/Maintenance(1)		
		Each Use	Replace/ Repair(2)	Annual
CCV containment O-rings (lid & port)	8.2.3.1	V, LT1	LT2	R, LT2
CCV leak test O-rings (lid & port)	8.2.3.1	V		R
CCV containment O-ring sealing surfaces	8.2.3.2	V	LT2	V
CCV leak test O-ring sealing surfaces	8.2.3.2	V		V
CCV lid bolts	8.2.3.3	V	F	V
Threaded inserts for CCV lid bolts	8.2.3.3		F	V
CCV port cover	8.2.3.3	V	F	V
OSV lid bolts	8.2.3.3	V	F	V
Threaded inserts for OSV lid bolts	8.2.3.3		F	V
Tapped holes(3)	8.2.3.3		F	
Impact limiter attachments	8.2.3.3	V	F	V
Exposed packaging exterior surfaces	8.2.3.4	V		V
Exposed interior and exterior surfaces	8.2.3.4			V

Notes:
1. R = Replace, V = Visual Inspection, F = Functional Test, LT1 = Pre-shipment leak test (Section 7.4.2), LT2 = maintenance/periodic leak test (Section 8.2.2.1).
2. Tests or inspections necessary when items are replaced or repaired.
3. Tapped holes without threaded inserts.

8.3 Appendix

8.3.1 References

[8.1] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, *Class 1 Components*, 2010 Edition with 2011 Addenda.

[8.2] ASTM International, D1622/D1622M-14, *Standard Test Method for Apparent Density of Rigid Cellular Plastic*.

[8.3] ASTM International, D1621-14, *Standard Test Method for Compressive Properties of Rigid Cellular Plastic*.

[8.4] ASTM International, E709-15, *Standard Practice for Magnetic Particle Testing*.

[8.5] ASTM International, E165/E165M-12, *Standard Practice for Liquid Penetrant Examination for General Industry*.

[8.6] ANSI N14.5-2014, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*, American National Standards Institute, Inc., June 19, 2014.

[8.7] ASME Boiler and Pressure Vessel Code, Section V, *Nondestructive Examination*, Subsection A, *Nondestructive Methods of Examination*, 2013 Edition, July 1, 2013.

[8.8] ASTM International, A874/A874M-98, *Standard Specification for Ferritic Ductile Iron Castings Suitable for Low-Temperature Service*.

[8.9] Danish Standard, DS/EN 12680-3, *Founding – Ultrasonic testing – Part 3: Spheroidal graphite cast iron castings,* latest edition.

[8.10] ASTM International, A247, *Standard Test Method for Notched Bar Impact Testing of Graphite in Iron Castings,* latest edition.

[8.11] ASTM International, E23, *Standard Test Method Plane-Strain Fracture Toughness of Metallic Materials,* latest edition.

[8.12] British Standards Institute, BS EN 1563:2018, *Founding – Spheroidal Graphite Cast Irons*.

[8.13] ASTM International, A327, *Standard Test Method for Impact Testing of Cast Irons,* latest edition.

This page intentionally left blank.