PUBLIC VERSION

RT-200 Type B Cask
Safety Analysis Report

Docket Number 71-9384
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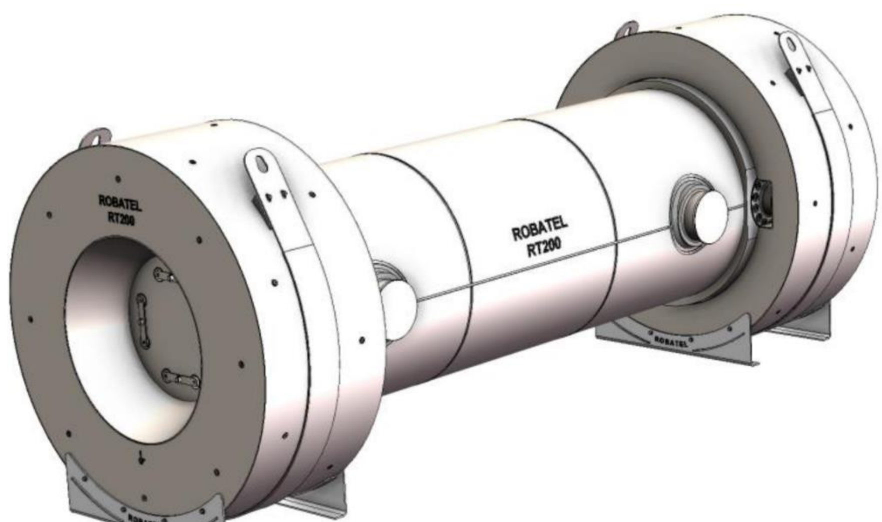
Revision 0



This Part 71 Application for Approval of the RT-200 Type B Cask Package for Radioactive Material represents Robatel Technologies, LLC approach to its business as applied to the specifications of this submittal. This Application requests that the Nuclear Regulatory Commission respects the proprietary information and withholds it from public disclosure subject to the provisions of 10 CFR 2.390. All detailed drawings are considered proprietary information.

0. INTRODUCTION

0.1. TABLE OF CONTENTS

0.2. LIST OF FIGURES

[redacted]

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The SAR contains proprietary references that Robatel requests be withheld from public disclosure under 10 CFR 2.390: when applicable, references are clearly identified as “(PROPRIETARY)”.

This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

To provide comprehensive overview, all references the SAR refers to are summarized hereafter (knowing that detailed lists of each chapter references are provided in the chapters first appendices section*).

* *Documents may be referenced in several chapters: in such a case, several reference numbers may be assigned to a single document. The summary list below concatenates all references over the SAR but removing duplicates if any. This list doesn't therefore include any reference number: numbering is implemented further over the SAR chapters.*

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0.5. List of Acronyms

ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASNT	American Society for Nondestructive Testing
ASTM	American Society for Testing and Materials
COFREND	French Confederation for Non-Destructive Testing
CFR	US Code of Federal Rules
[redacted]	
DOT	US Department Of Transportation
FE(M)(A)	Finite Elements (Model) (Analysis)
HAC	Hypothetical Accident Conditions
IAEA	International Atomic Energy Agency
ISO	International Organization for Standardization
[redacted]	
MCNP®	Monte Carlo N-Particle® *(code developed by Los Alamos National Laboratory)*
MNOP	Maximum Normal Operating Pressure *(according to 10 CFR 71.4 definition)*
NCT	Normal Conditions of Transport
NDT	Non-Destructive Testing
[redacted]	
NRC	US Nuclear Regularory Commission
NUREG	U.S. Nuclear Regulatory Commission technical report designation
RAM	RAdioactive Material
RG	U.S. Nuclear Regulatory Commission Regulatory Guide
RI	ROBATEL Industries
RT	ROBATEL Technologies
SAR	Safety Analysis Report of the RT-200 package

SC	Storage Container
STB	STellite Box
TRU (waste)	TRansUranic (waste)

[redacted]

0.6. LIST OF UNITS

SI metric units are used throughout the SAR. Calculations or reference sources can also refer to other units as described in the table below.

Table 0.6-1 Main units

Unit / Physical constant		SI / metric Unit
	Length:	
1 μm (micrometer)	=	10^{-6} m
1 mm (millimeter)	=	10^{-3} m
1 cm (centimeter)	=	10^{-2} m
1 dm (decimeter)	=	10^{-1} m
1 in = 1” (inch)	=	2.54 x 10^{-2} m (= 2.54 cm)
1 ft = 1’ (foot = 12 in)	=	3.048 x 10^{-1} m (= 30.48 cm)
	Mass:	
1 g (gram)	=	10^{-3} kg
1 t (metric ton)	=	10^{3} kg
1 lb (pound)	=	0.4536 kg
	Density:	
1 pcf (pound per cubic foot)	=	16.018 kg/m^3
	Force:	
1 daN (decanewton)	=	10 N
1 kN (kilonewton)	=	10^{3} N
	Pressure:	
1 mPa (millipascal)	=	10^{-3} Pa
1 kPa (kilopascal)	=	10^{3} Pa
1 MPa (megapascal)	=	10^{6} Pa
1 GPa (gigapascal)	=	10^{9} Pa
1 mbar (millibar)	=	10^{2} Pa
1 bar	=	1 x 10^{5} Pa
1 atm (atmosphere)	=	1.01325 x 10^{5} Pa
1 psi (pound per square inch)	=	6.8948 x 10^{3} Pa
1 ksi (kilopound per square inch)	=	6.8948 x 10^{6} Pa (= 10^{3} psi)
	Temperature:	
°C (Celsius) or °F (Fahrenheit)	⇔	°K (Kelvin)

Unit / Physical constant		SI / metric Unit
Temperature scales systems:		
[T(°F) - 32] x 5/9	=	T(°C)
T(°C) + 273.15	=	T(°K)
	Energy:	
1 eV (electronvolt)	=	1.602177 x 10^{-19} J
1 MeV (Megaelectronvolt)	=	1.602177 x 10^{-13} J (= 10^{6} eV)
1 BTU (British Thermal Unit)	=	1,055.06 J
1 cal (calorie)	=	4.187 J
1 g cal/cm² (gram calorie per square centimeter)	=	41,870.0 J/m²
	Time:	
1 μs (microsecond)	=	10^{-6} s
1 ms (millisecond)	=	10^{-3} s
1 min (minute)	=	60 s
1 h (or hr = hour)	=	3,600 s
1 d (day)	=	86,400 s (= 24 h)
1 yr (year)	=	31,557,600 s (= 365.25 d)
	Nuclear / radiation:	
1 mSv (millisievert)	=	10^{-3} Sv (sievert)
1 rem (roentgen equivalent man)	=	10^{-2} Sv = 10 mSv
1 mrem (millirem = 10^{-3} rem)	=	0.01 mSv
1 Ci (curie)	=	3.7 x 10^{10} Bq (becquerel)
1 TBq (terabecquerel)	=	10^{12} Bq
1 rad (radiation absorbed dose)	=	0.01 Gy (gray)
1 Gy (gray)	=	1 J/kg
	Other:	
1 ref-cm³ (reference cubic centimeter)	=	1 cm³ of dry air at 1 atm (abs) and 25°C (= 0.101325 Pa·m³ at 25°C)
1 cP (centipoise)	=	10^{-3} Pa·s
1 mol (mole)	=	6.022 x 10^{23} molecules
1 gmol (gas mole)	=	1 mol (of gas)

0.7. REVISION LOG

Rev.	***Date***	***Details***
0	02/28/2024	First issue

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1. GENERAL INFORMATION

Robatel Technologies LLC (RT) requests an evaluation and approval from the Nuclear Regulatory Commission (NRC) of this 10 CFR 71 Application for the Model RT-200 Cask Type B(U) Package (hereinafter RT-200) for shipment of radioactive material.

The following 10 CFR 71 [Ref. 1] application describes the design and operation of the RT-200 cask. The objective of this chapter is to provide general information that feeds into later sections in this application according to Figure 1.1-1.

Table of Content

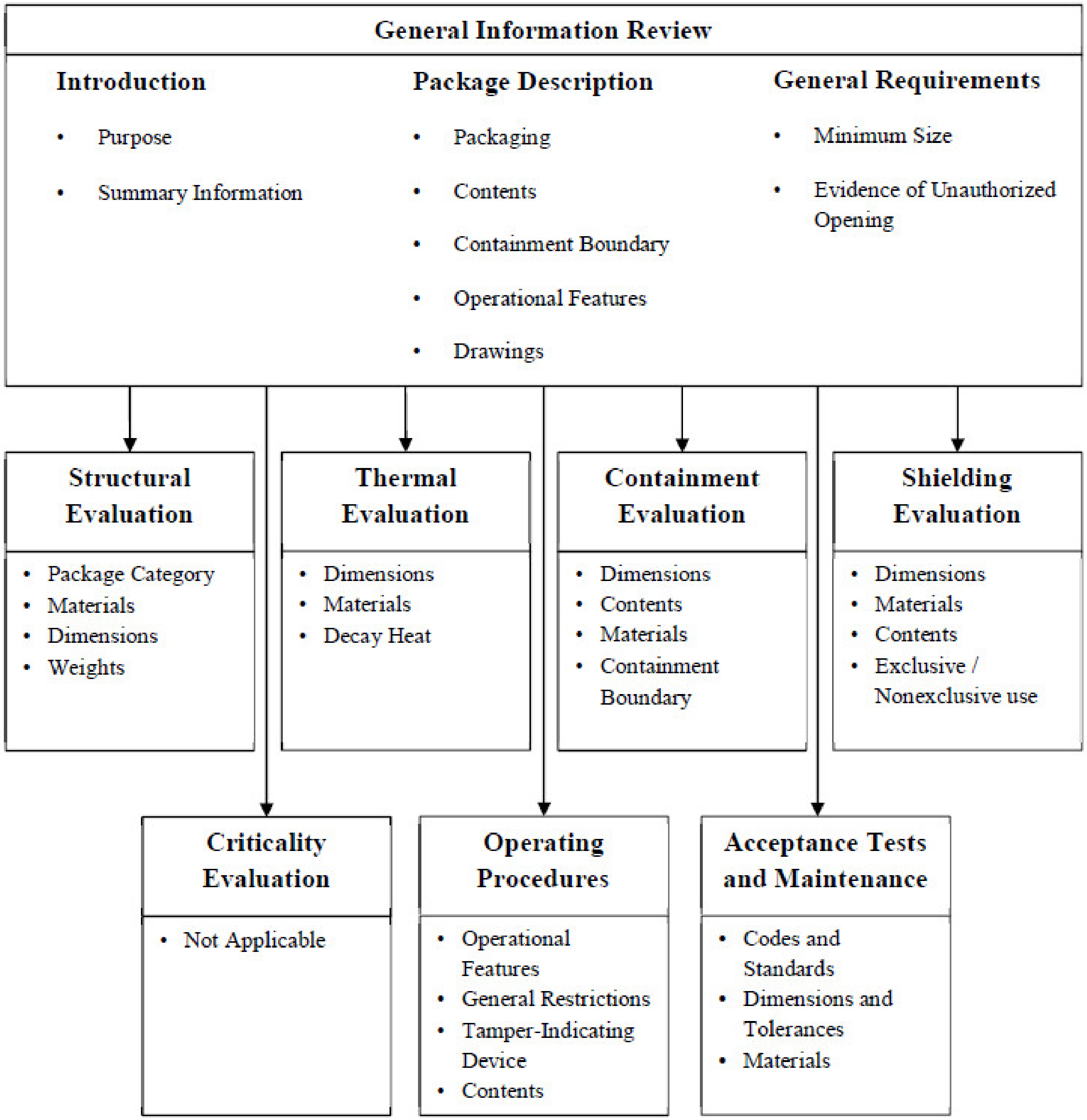
1.1. INTRODUCTION

The RT-200 cask is designed and engineered to package and transport solid irradiated and contaminated non-fuel-bearing materials and stellite boxes in storage containers, and miscellaneous solid irradiated and contaminated non-fuel-bearing hardware. The proposed cask model number is “RT-200”.

This application does not request the packaging and/or transport of fissile material in quantities exceeding those exempted from consideration in accordance with 10 CFR 71.15 [Ref. 1] and thus the Criticality Safety Index (CSI) is non-applicable.

The RT-200 is designed to transport radioactive materials in normal form (e.g. neither LSA nor special form) in quantities less than 3,000 A_2 and not exceeding 30,000 Ci (1.11E+15 Bq). Consequently, in accordance with Table 4 of NUREG/CR-6407 [Ref. 8], RT-200 packaging is classified as Category II.

Figure 1.1-1 Information flow for general information



1.2. PACKAGE DESCRIPTION

Section 1.2 provides a summary of all design aspects of the RT-200. A general arrangement of the RT-200 cask is included in Appendix 1.3.2. The general arrangement depicts the package dimensions and construction materials. Figure 1.2-1 shows the major components of the RT-200 as an exploded view with the various components labeled.

Compliance with the requirements specified in 10 CFR Part 71, Subpart E under the tests and conditions in Subpart F is addressed in Table 1.2-1, which lists the requirements and provide a reference to the sections of this document that are used to specifically address compliance with the requirements.

Table 1.2-1 RT-200 compliance with 10 CFR Part 71, Subpart E requirements

§ 10 CFR Part 71		SAR Sections
71.41	(a)	2.6 2.7 3.3 3.4
	(b)	1.2.1.7 7.3
	(c)	Not applicable
	(d)	Not applicable
71.43	(a)	2.4.1
	(b)	2.4.2
	(c)	2.4.3
	(d)	1.2.2.1.6 1.2.2.2.6 0
	(e)	4.1.2
	(f)	2.6
	(g)	3.1.3
	(h)	4.1.4
71.45	(a)	2.5.1
	(b)	2.5.2
71.47	(a)	Not applicable
	(b)	5.1.2
	(c)	7.1
	(d)	7.1
71.51	(a)	
	(1)	4.3
	(2)	5.1.2
	(b)	1.2.2.1.1 1.2.2.2.1
	(c)	1.2.1.3
	(d)	*Not applicable*
71.55		*Not applicable*
71.59		*Not applicable*
71.61		*Not applicable*
71.63		*Not applicable*
71.64		*Not applicable*
71.65		*Not applicable*

1.2.1. Packaging

Section 1.2.1 provides details regarding overall dimensions, weight, containment, shielding, criticality, structural features, heat transfer features, and package markings.

1.2.1.1. Main Cask Components

The package consists of a stainless-steel and lead cylindrical shipping cask with a pair of cylindrical foam-filled impact limiters installed on each end. The package configuration is shown in Figure 1.2-1.

Figure 1.2-1 RT-200 Cask package exploded view

[redacted]

The main package dimensions and thicknesses are listed in Table 1.3-2 and Table 1.3-3.

The cylindrical cask body consists of an outer stainless-steel shell and an inner stainless-steel plate. The annular space between the shells is filled with lead.

The rear of the cask consists of a stainless-steel forging.

The lid consists of a stainless-steel forging. The lid is fastened to the cask body (on the stainless-steel front forging flange) with thirty (30) M42 round head hex bolts.

The two impact limiters consist of stainless-steel casings filled with the foam. Each impact limiter is fastened to the cask (cask body on the rear and cask lid on the front) with eight (8) M42 round head hex bolts. These bolts are secured in pairs with bolt securing plates and safety seals. If intact, this provides evidence that unauthorized persons have not opened the package.

1.2.1.2. Weight

The maximum gross weight of the RT-200 including impact limiters is 76,500 kg (including the maximum payload weight of 8,400 kg). The maximum (empty) weight of the RT-200 including impact limiters is 68,100 kg.

Details of the main package component weights are presented in Table 1.3-1. Nominal weights are indicated as well as the maximum weight for each element (bounding weight takes into account the tolerances on the geometries and the densities of the various components).

1.2.1.3. Containment Features

The containment features of the RT-200 consist of the inner shell, rear forging, front forging flange, cask lid, vent and drain port cover plates, double O-ring seals, and closure bolts. The containment boundary is shown in Figure 4.6-1. The containment system prevents leakage of radioactive material from the cask cavity and allows pre-shipment leakage testing of the assembled cask configuration.

1.2.1.4. Neutron and Gamma Shielding Features

The RT-200 is not designed to carry fissile material or neutron sources (except typical small quantities consistent with the contents as discussed in Chapter 5) and thus provision of neutron shielding is not required for the RT-200.

The RT-200 cask provides adequate shielding against gamma radiation due to the thickness of stainless-steel and lead of the constituent elements of its body, detailed in Table 1.3-3, in particular:

- the inner shell,
- the outer shell,
- the lead between the inner and outer shell,
- the rear and front forgings,
- the lid.

Furthermore, but to a lesser extent, the following stainless-steel elements are complementary to the overall shielding:

- the thermal shield plate,
- the structures of the impact limiters.

Contents are limited such that the radiological shielding provided assures compliance with U.S. Department of Transportation (DOT) regulatory requirements.

1.2.1.5. Shielding Features for Personnel Barriers

The RT-200 does not require the use of personnel barriers to meet 10 CFR 71 dose rate limits.

1.2.1.6. Criticality Control Features

The RT-200 contents are irradiated and contaminated non-fuel-bearing materials or hardware from commercial nuclear power plants that contain only trace quantities of fissile radionuclides. As such, the contents meet the requirements of 10 CFR 71.15 [Ref. 1] and are exempt from classification as fissile material. As a result, the RT-200 does not require any criticality control features.

1.2.1.7. Structural Features – Lifting and Tie-down Devices

The RT-200 cask employs lifting devices that are a structural part of the package. A pair of trunnions are bolted on the front forging to lift the cask. A belt guide is bolted to the impact limiters. Removable lifting lugs are utilized for removal and handling of the lid. Refer to Chapter 2, Section 2.5.1 for a detailed analysis of the structural integrity of the lifting devices.

Two pairs of trunnions are welded to the cylindrical cask body to tie-down the cask and are considered as a structural part of the package. Refer to Chapter 2, Section 2.5.2 for a detailed analysis of the structural integrity of the tie-down trunnions.

1.2.1.8. Structural Features – Impact Limiters

Impact limiters are overall a cylindrical shape. They cover and protect the two ends of the cask and extend from the front and rear beyond the body and the cask lid. The impact limiter external shells are stainless-steel, allowing them to withstand large plastic deformation without fracturing. The volume inside the shell is filled with crushable shock-absorbing and thermal-insulating foam. [redacted]

The impact limiters are attached to the cask via eight (8) M42 round head hex bolts to the lid and to the rear forging. These bolts are secured in pairs with bolt securing plates and safety seals (see Appendix 1.3.4, folio 10). If intact, this provides evidence that unauthorized persons have not opened the package.

1.2.1.9. Structural Features – Internal Supporting of Positioning Features

When it is loaded with Content No. 1, the RT-200 cask interior has positioning features as detailed in Figure 1.2-4. The radioactive material shall be pre-packaged in storage containers as defined in section 1.2.2.1 and placed into the cask cavity. The storage containers shall be loaded into a disposable insert, which shall be loaded into the basket as shown in Figure 1.2-4. This configuration provides adequate structural stability to meet DOT requirements.

When it is loaded with Content No. 2, the RT-200 cask interior has no specific supporting or positioning features required. The contents loaded into the cask cavity may require appropriate shoring to prevent movement during transit. It is the responsibility of the shipper to provide adequate shoring that meets DOT requirements.

1.2.1.10. Structural Features – Outer Shell or Outer Packaging

The external surface of the cylindrical cask body consists of a stainless-steel outer shell whose thickness is presented in Table 1.3-3.

1.2.1.11. Structural Features – Packaging Closure Device

The main packaging closure device is the lid which consists of a stainless-steel forging as described in Section 1.2.1.1 and detailed in Table 1.3-3. The lid is fastened to the cask body with thirty (30) M42 round head hex bolts.

The cask also has two ports to vent and drain its cavity (located in the front and rear forgings). They are each closed and sealed by a stainless-steel cover plate that is fastened to the cask body with six (6) M16 round head hex bolts.

1.2.1.12. Structural Features – Heat Transfer Features

The RT-200 relies on the insulating properties of the impact limiter foam and the cask body ceramic fiber thermal shield to minimize heat input during the hypothetical fire accident event. See Chapter 3, Section 3.4 for details.

There are no special features designed to dissipate heat from the cask.

1.2.1.13. Structural Features – Packaging Markings

The side of the cask body is marked with the Model Number of the cask “RT-200”, the Certificate of Compliance No., Empty Weight, Type B(U), UN 2916 and other required data.

1.2.1.14. Additional Information

- RT-200 cask is depicted in the engineering drawings provided in Appendix 1.3.
- Pressure test ports are provided between the twin O-rings for the lid and between the twin O-rings for the vent and drain port cover plates. These ports facilitate leak testing of the package in accordance with ANSI N14.5 [Ref. 2].
- The vent and drain ports are provided for draining water and venting pressures within the containment cavity which may be generated during transport and prior to lid removal. Each port is sealed with an elastomer O-ring. Specification information for all O-rings is contained in Chapter 4, Section 4.1.3.
- The RT-200 does not rely on any coolants to perform its function of providing safe transportation of its radioactive contents.
- There are no external/internal protrusions other than the belt guide and trunnions previously described.
- Classification of components according to importance to safety is done according to NUREG classification [Ref. 8] and detailed in the Bill of Materials (see Appendix 1.3.3).
- Bolt torques are listed in Table 1.3-5 in Appendix 1.3.8.

1.2.2. Contents

The authorized contents of the RT-200 are generally described in this section. The radioactive contents in normal form are described to the extent required to demonstrate compliance with 10 CFR 71 requirements relating to the structural, thermal and shielding performance of the cask.

Table 1.2-2 below lists the various content types that can be carried in the RT-200 packaging which are subsequently detailed individually in the following related sections.

Table 1.2-2 Summary of the RT-200 Radioactive Content

Content number	***Content Type***	***Section reference***
1	Solid irradiated and contaminated non-fuel-bearing materials and Stellite Boxes in Storage Containers	1.2.2.1
2	Miscellaneous solid irradiated and contaminated non-fuel-bearing hardware in secondary containers	1.2.2.2

1.2.2.1. Content No. 1

This section includes a description of Content No. 1 of the RT-200, in compliance with the requirements specified in 10 CFR Part 71.33(b) [Ref. 1] and summarized in Table 1.2-3.

Table 1.2-3 Content No. 1 of the RT-200 compliance with 10 CFR Part 71.33(b)

71.33(b)	**Justification**	**Sections**
(1) Identification and maximum radioactivity of radioactive constituents.	30,000 Ci (1.11E+15 Bq) and 3,000 A2	1.2.2.1.1
(2) Identification and maximum quantities of fissile constituents.	15 grams.	1.2.2.1.2
(3) Chemical and physical form.	Solid metallic hardware which may contain residual water	1.2.2.1.3
(4) Extent of reflection, the amount and identity of nonfissile materials used as neutron absorbers or moderators, and the atomic ratio of moderator to fissile constituents.	Nonfissile materials are not used as neutron absorbers or moderators	1.2.2.1.5
(5) Maximum normal operating pressure.	200 kPa absolute	1.2.2.1.7
(6) Maximum weight.	8,400 kg	1.2.2.1.8
(7) Maximum amount of decay heat.	1,200 W	1.2.2.1.9
(8) Identification and volumes of any coolants.	N/A	N/A

Content No. 1 of the RT-200 packaging consists of three (3) Storage Containers (SCs) packaged in Disposable Insert No. 1 and Basket No. 1 as follows.

The SCs are parallelepiped boxes made of stainless steel. An SC may be loaded with one Stellite Box (STB), which is a smaller parallelepiped box equipped with an internal basket and constructed entirely of stainless steel. When present, the STB is placed at the bottom of the SC, and then the SC is loaded with solid irradiated and contaminated non-fuel-bearing materials. The SCs[1] are filled with conforming material, and then additional bracing is added to prevent contents from shifting during transport.

General illustrations are provided by Figure 1.2-2 and Figure 1.2-3.

Both the SC and the STB are closed using covers fixed by bolts which creates a positive closure to prevent content from escaping the confines of the SC or the STB.

Both the SC and the STB include drain holes at the bottom that are finer than any loaded content so water is easily removed by gravity, but contents are prevented from escaping.

The main physical features of the SCs are summarized in Table 1.2-4. Their design is detailed by the drawings and figures listed below:

– RT-200 Content No. 1 internals:	[Ref. 5]	Figure 1.2-4
– Storage Container (SC):	[Ref. 7]	Figure 1.2-4 Figure 1.2-2
– Stellite Box (STB) + Basket:		Figure 1.2-3

Table 1.2-4 Content No. 1 internals main physical features

Component	***Material***	***General external dimensions (mm)***	***Bounding empty mass (kg)***
Basket No. 1	Stainless-steel	Ø = 1080 x H = 4565	2,500
Disposable insert No. 1	Stainless-steel	W = 730 x L = 820 x H = 4680	800
SC	Stainless-steel	W = 318 x L = 438 x H = 4515	400*
STB	Stainless-steel	W = 222 x L = 340 x H = 289	110**

* *(this weight corresponds to an empty SC: without content or STB)*

** *(this weight includes the small metallic basket which is used to hold the radioactive pieces within the STB and which weighs about 2 kg)*

The following sections describe typical configurations of an SC and the main features of its constituent contents.

[1] Contents shall be close fitting to prevent both radial and axial movements during transport.

Figure 1.2-2 Arrangement configurations within a Storage Container (SC)

[redacted]

Figure 1.2-3 Stellite Box illustrations (STB & its basket)

[redacted]

Figure 1.2-4 RT-200 Content No. 1 Internals overview

[redacted]

1.2.2.1.1. *Identification and Maximum Quantities of the Radioactive Material*

The maximum total activity of Content No. 1 (including 3 SCs) is limited to 30,000 Ci (1.11E+15 Bq) and 3,000 A2. This is compliant with a Type B quantity of radioactive material as defined by 10 CFR 71.4 [Ref. 1].

^{60}Co is the principal gamma emitter nuclide within the SC's content that overwhelmingly contributes to the maximum radiation levels around a SC with a contribution greater than 99%.

The quantity of radioactive material within the RT-200 for Content No. 1 is limited by the maximum amount of radioactive material that corresponds to the external radiation standards as defined in 10 CFR 71.47 [Ref. 1]. The cask operator must follow the procedures outlined in Chapter 7 to ensure personnel safety and regulatory compliance.

1.2.2.1.2. *Identification and Maximum Quantities of the Fissile Material*

The maximum quantity of fissile material within Content No. 1 (total of 3 SCs) is limited to 15 grams.

Content No. 1 is therefore exempt from the classification as fissile material by 10 CFR 71.15(b) [Ref. 1] provided that the package has at least 200 grams of solid nonfissile material for every gram of fissile material.

1.2.2.1.3. *Chemical and Physical Form / Density / Moisture Content / Moderators*

The content is solid: there is no gas or liquid. It is mainly metallic hardware that has been irradiated and/or contaminated. Examples include:

[redacted]

The content is mainly made from stainless-steel, Stellite or Inconel but can also contain small amounts of other material [redacted] The metallic material densities are comprised between 7 and 9 kg/dm³ roughly.

The RT-200 will not transport fissile material as stated in Section 1.2.2.1.2 and therefore no moderating constituents will be used in the RT-200.

The RT-200 may contain a residual water content due to underwater loading. The residual water content is further defined in Section 1.2.2.1.6.

1.2.2.1.4. *Location and Configuration of Contents within the Packaging*

The loading configuration for Content No. 1 allows up to 3 SCs to be loaded into a disposable insert (Disposable Insert No. 1) and shored with a dedicated basket (Basket No. 1).

The dedicated basket shores the disposable insert in place and prevents it from shifting during transportation. The disposable inserts shore the storage containers in place. The storage containers shore the content in place.

The basket is evaluated to ensure that it will adequately shore the Disposable Inserts and its content under normal conditions for transport and hypothetical accident conditions (see Appendix 2.12.5). The disposable insert and its related basket are both stainless-steel structures. There is no restriction on the angular position of the Basket No. 1 inside the packaging's cavity.

1.2.2.1.5. *Use of Nonfissile Materials as Neutron Absorbers/Moderators*

Nonfissile materials are not used as neutron absorbers or moderators.

1.2.2.1.6. *Chemical / Galvanic / Gas Generation*

Content No. 1 does not include materials that may cause any significant chemical, galvanic, or other reaction.

According to Chapter 7 "Package Operations", the RT-200 packaging can be loaded underwater. In such a case, the package must be drained according to specific operation instructions. However, some amount of residual water or moisture will remain inside its cavity. A water radiolysis reaction might then lead to combustible gases generation within the package. To limit the hydrogen gas generation, a maximum quantity of 5 % hydrogen by volume at standard temperature and pressure is allowed. The time duration is calculated as twice the expected shipment time.

This gas generation is assessed in the section 4.5 of the SAR. It is calculated using the methods in NUREG/CR-6673 [Ref. 3] which provides equations that allow prediction of the hydrogen concentration within the package's cavity as a function of time. The inputs to these equations mainly include the bounding effective $G(H_2)$-value for water, the void volume in the containment vessel, the temperature when the package was sealed and the content's decay heat.

The shipment period begins when the package is prepared (sealed) and is completed within a time period that is half the time used in the hydrogen generation calculation. It is the shipper's responsibility to ensure that hydrogen generation in the cavity will be below 5% by volume, representing the lower flammability limit for hydrogen. The maximum allowable shipping time is not restricted for any other reason. A detailed discussion of the hydrogen generation calculations is provided in Chapter 4, Section 4.5, and Chapter 7, Section 7.5.

1.2.2.1.7. *Maximum Normal Operating Pressure (CFR 71.33.(b)(5))*

The MNOP of the RT-200 packaging when loaded with Content No. 1 is assessed within section 3.3.2. These calculations also include the maximum gas generation within the content that might result from radiolysis of moisture or residual water if any.

1.2.2.1.8. *Maximum Weight of Radioactive Content and Payload*

The maximum weight of 1 SC is limited to 1,700 kg. This includes its maximum contents (radioactive material + inner structures) whatever the packing arrangement is within the SC (e.g., including one STB).

The maximum gross weight of the packaging payload is limited to 8,400 kg. This includes the disposable insert No. 1, its dedicated basket No. 1, 3 SCs and their maximum contents, whatever the packing arrangement is within the SCs (see weights details in Table 1.3-1).

1.2.2.1.9. *Maximum Decay Heat*

The maximum decay heat of the RT-200 Content No. 1 is limited to 1,200 W (total).

1.2.2.1.10. *Loading Restrictions*

As required by 10 CFR 71.43(d) [Ref. 1], the contents do not include materials that may cause any significant chemical, galvanic, or other reactions.

1.2.2.1.11. *Content No. 1 Summary*

The type and form of material is defined as irradiated and contaminated solid hardware [redacted] contained within Storage Containers packed into the RT-200 using a dedicated disposable insert and associated basket. Up to 3 Storage Containers can be loaded into the packaging.

The maximum quantity of payload material including contents, Storage Containers, the disposable insert and its dedicated basket is 8,400 kg.

The maximum quantity of material is defined as a Type B quantity of radioactive materials not to exceed 3,000 A2 and 30,000 Ci.

The quantity of radioactive material within the RT-200 for Content No. 1 is limited by the maximum amount of radioactive material that corresponds to the external radiation standards as defined in 10 CFR 71.47 [Ref. 1]. The cask operator must follow the procedures outlined in Chapter 7 to ensure personnel safety and regulatory compliance.

The contents may include fissile materials provided that at least one of the paragraphs (a) through (f) of 10 CFR 71.15 [Ref. 1] is met.

1.2.2.2. Content No. 2

This section includes a description of Content No. 2 of the RT-200, in compliance with the requirements specified in 10 CFR Part 71.33(b) [Ref. 1] and summarized in Table 1.2-5.

Table 1.2-5 Content No. 2 of the RT-200 compliance with 10 CFR Part 71.33(b)

71.33(b)	Justification	Section
(1) Identification and maximum radioactivity of radioactive constituents.	• 30,000 Ci (1.11E+15 Bq) and 3,000 A2, and • 10 Ci/kg (0.37 TBq/kg) – Co-60 equivalent	1.2.2.2.1
(2) Identification and maximum quantities of fissile constituents.	Limits specified in 10 CFR 71.15	1.2.2.2.2
(3) Chemical and physical form.	Non-fuel-bearing solid hardware which may contain residual water	1.2.2.2.3
(4) Extent of reflection, the amount and identity of nonfissile materials used as neutron absorbers or moderators, and the atomic ratio of moderator to fissile constituents.	Nonfissile materials are not used as neutron absorbers or moderators	1.2.2.2.5
(5) Maximum normal operating pressure.	200 kPa absolute	1.2.2.2.7
(6) Maximum weight.	8,400 kg	1.2.2.2.8
(7) Maximum amount of decay heat.	1,200 W	1.2.2.2.9
(8) Identification and volumes of any coolants.	N/A	N/A

1.2.2.2.1. <u>Identification and Maximum Quantities of the Radioactive Material</u>

The maximum quantity of material within Content No. 2 is limited to 30,000 Ci (1.11E+15 Bq) and 3,000 A2. This is compliant with a Type B quantity of radioactive material as defined by 10 CFR 71.4 [Ref. 1].

The local[1] specific activity of the contents is limited to 0.37 TBq/kg of Co-60 or equivalent (10 Ci/kg). This means that the most activated portion of any single waste item must be less than or equal to this specific activity limit. Equivalence is described in Section 5.5.2.

[1] The user shall verify prior to loading the RT-200 cask that the specific activity of the waste components to be loaded has been pre-calculated (e.g. calculated prior to loading the RT-200 cask) using a widely-recognized radiation-safety source-term computer code(s) that is accompanied by design control measures for ensuring the quality of computer programs. The “pre-calculation” is required to ensure maximum waste activity and decay heat comply with the maximum values specified (respectively in present section and section 1.2.2.2.9).

1.2.2.2.2. *Identification and Maximum Quantities of the Fissile Material*

Content No. 2 may include fissile material up to the limits specified in 10 CFR 71.15 [Ref. 1] such that Content No. 2 is exempt from the classification as fissile material.

1.2.2.2.3. *Chemical and Physical Form / Density / Moisture Content / Moderators*

Content No. 2 may contain irradiated and contaminated non-fuel-bearing solid hardware. The radioactive material is primarily in the form of neutron activated metals, or metal oxides in solid form. Surface contamination may also be present on the irradiated components.

When a wet load procedure (e.g., in-pool) is followed for cask loading, cask cavity draining is performed to limit the liquid content to a small amount in the package during transport. The residual water content is further defined in Section 1.2.2.2.6.

1.2.2.2.4. *Location and Configuration of Contents within the Packaging*

Content No. 2 materials can be packed into secondary containers or shoring to be loaded inside the cask. The RT-200 cask is normally filled to capacity, which prevents shifting of the contents during transport. If not full, appropriate component spacers or shoring will be used to prevent significant shifting of the contents.

The safety analysis of the package takes no credit for the containment or shielding possibly provided by secondary containers.

1.2.2.2.5. *Use of Nonfissile Materials as Neutron Absorbers/Moderators*

Nonfissile materials are not used as neutron absorbers or moderators.

1.2.2.2.6. *Chemical / Galvanic / Gas Generation*

Material that is subject to chemical, galvanic or other reactions is prohibited within Content No. 2.

According to Chapter 7 “Package Operations”, the RT-200 packaging can be loaded underwater. In such a case, specific operation instructions are defined so that it must be drained before transportation, however some amount of residual water or moisture will remain inside its cavity. A water radiolysis reaction might then lead to combustible gases generation within the package. To limit the hydrogen gas generation, a maximum quantity of 5% hydrogen by volume at standard temperature and pressure is allowed. The time duration is calculated as twice the expected shipment time.

This gas generation is specifically assessed in Section 4.5 of the SAR. It is calculated using the methods in NUREG/CR-6673 [Ref. 3] which provides equations that allow prediction of the hydrogen concentration within the package’s cavity as a function of time. The inputs to these equations mainly include the bounding effective $G(H_2)$-value for water, the void volume in the containment vessel, the temperature when the package was sealed and the contents decay heat.

The shipment period begins when the package is prepared (sealed) and is completed within a time period that is half the time used in the hydrogen generation calculation. It is the shipper's responsibility to ensure that hydrogen generation in the cavity will be below 5% by volume, representing the lower flammability limit for hydrogen. The maximum allowable shipping time is not restricted for any other reason. Detailed discussion of the hydrogen generation calculations is provided in Chapter 4, Section 4.5, and Chapter 7, Section 7.5.

1.2.2.2.7. *Maximum Normal Operating Pressure (CFR 71.33.(b)(5))*

The MNOP of the RT-200 packaging when loaded with Content No. 2 is assessed within Section 3.3.2.

1.2.2.2.8. *Maximum Weight of Radioactive Content and Payload*

The maximum payload is 8,400 kg. This includes both the radioactive materials of Content No. 2 as well as the secondary containers, internals or shoring components if any, whatever the packing arrangement is.

1.2.2.2.9. *Maximum Decay Heat*

The maximum total decay heat of the RT-200 Content No. 2 is limited to 1,200 W.

1.2.2.2.10. *Loading Restrictions*

Material that presents other risks than those related to its radioactive features is prohibited for Content No. 2. This especially includes explosives, non-radioactive pyrophoric materials, and corrosives (pH less than 2 or greater than 12.5). Pyrophoric radionuclides may be present only in residual amounts less than 1 % by weight. Materials that may auto-ignite or undergo phase transformation at temperatures less than 140°C, with the exception of water, are not included in the contents.

As required by 10 CFR 71.43(d) [Ref. 1], the contents do not include materials that may cause any significant chemical, galvanic, or other reactions.

The use of coolants within the packaging is prohibited as well.

1.2.2.2.11. *Content No. 2 Summary*

The type and form of material is defined as irradiated and contaminated solid components, mainly metallic, possibly packed into secondary containers and using appropriate component spacers or shoring to prevent shifting of the contents as needed.

The maximum quantity of payload material including contents, secondary containers and the appropriate component spacers or shoring is 8,400 kg.

The maximum quantity of material is defined as a Type B quantity of radioactive materials not to exceed 3,000 A_2 and 30,000 Ci.

The activity of gamma, neutron and beta emitting radionuclides does not exceed the limits established in the shielding evaluation provided in Chapter 5.

The contents may include small amounts of fissile materials in accordance with 10 CFR 71.15 [Ref. 1].

1.2.3. Special Requirements for Plutonium

The RT-200 package will not contain plutonium more than 0.74 TBq (20 Ci). Therefore, the requirements of 10 CFR 71.63 [Ref. 1] do not apply for the shipments of RT-200 packages.

1.2.4. Operational Features

The RT-200 has no complex operational requirements. The various valves, connections, openings, seals and containment boundaries are depicted in the drawings provided in Appendix 1.3. There are no piping systems associated with the RT-200 cask.

1.3. APPENDIX

This appendix contains proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390. This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

1.3.1. List of References

This section provides a list of the documents that are referred to within the section 1 – “General Information”. A comprehensive summary list of the entire SAR references is provided in Section 0 – “Introduction”.

Some of the references listed below might contain proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390: when it is the case, the reference is then clearly identified "(PROPRIETARY)". This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

Ref. 1 U.S. Nuclear Regulatory Commission, 10 CFR Part 71 – Packaging and Transportation of Radioactive Material

Ref. 2 ANSI N14.5-2022, “American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment”, American National Standards Institute, Inc., 11 West 42nd Street, New York, NY

Ref. 3 NUREG/CR-6673, “Hydrogen Generation in TRU Waste Transportation Packages”, Anderson, B., Sheaffer, M., & Fischer, L., Lawrence Livermore National Laboratory, Livermore, CA, May 2000

Ref. 4 Robatel Industries, “RT-200 Transportation Package without content”, Assembly Drawing, RT-200 PC 001, Rev. D (PROPRIETARY)

Ref. 5 Robatel Industries, “RT-200 Transportation Package with Content No. 1”, Assembly Drawing, RT-200 PC 002, Rev. D (PROPRIETARY)

Ref. 6 Robatel Industries, “RT-200 cask – Body Assembly”, Detailed Drawing, 103622 PD 101100, Rev. B (PROPRIETARY)

Ref. 7 Babcock Services Inc., “Activated Services Storage Container”, AS-SC-SK03, Rev. C, 18/12/2023 (PROPRIETARY)

Ref. 8 NUREG/CR-6407, “Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety”, J. W. McConnell, Jr., A. L. Ayers, Jr., M. J. Tyacke, February 1996

Ref. 9 Robatel Industries, “RT-200 – Bolt preload”, Technical Note, RT-200 NTE 2006, Rev. A (PROPRIETARY)

1.3.2. RT-200 Package Main Weights, Dimensions and Thicknesses

Table 1.3-1 RT-200 packaging main weights

[redacted]

Table 1.3-2 RT-200 Main Package Dimensions

[redacted]

Table 1.3-3 RT-200 Main Package Thicknesses

[redacted]

Table 1.3-4 Centers of gravity locations for the RT-200 main assemblies

[redacted]

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1.3.3. RT-200 Bill of Materials [Ref. 4] (folios 1 to 4)

[redacted]

[redacted]

[redacted]

[redacted]

1.3.4. RT-200 Design Drawings [Ref. 4] (folios 5 to 13)

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

1.3.5. RT-200 with Content No. 1 Design Drawings [Ref. 5]

[redacted]

[redacted]

[redacted]

[redacted]

1.3.6. Storage Container Overall Assembly Drawing [Ref. 7]

[redacted]

1.3.7. RT-200 Cask Body Welds Identification ([Ref. 6], folio 2)

[redacted]

[redacted]

1.3.8. List of Bolted Elements and Preload Torques

[redacted]

2. STRUCTURAL EVALUATION

Chapter 2 describes the structural evaluation for the RT-200 and summarizes the results to demonstrate compliance with the structural requirements of 10 CFR 71 [Ref. 10]. These evaluations follow nuclear industry standards. Chapter 1 “General Information”, and Chapter 3 “Thermal Evaluation” provide input to the Chapter 2 “Structural Evaluation”; furthermore, these three chapters feed information to later Chapters of the SAR.

The foremost structural requirement of the RT-200 is to withstand Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) loadings with sufficient structural integrity to maintain shielded containment. Evaluations in the following sections demonstrate the RT-200 package design satisfies these requirements. Before presenting these detailed evaluations, a general description of the RT-200 cask design is provided and includes complete specifications for the containment boundary.

Table of Content

2.1. DESCRIPTION OF STRUCTURAL DESIGN

Major design features that govern the structural performance of the RT-200 cask under NCT and HAC conditions are the impact limiters (front and rear) and the cask body including the lid, lifting trunnions, and tie-down trunnions. These features are sufficiently designed so that the structural response of the RT-200 meets all 10 CFR 71 [Ref. 10] requirements.

Chapter 1 of the SAR provides a general description of the RT-200 package including its general assembly drawings [Ref. 11] and [Ref. 12] in the Chapter 1 appendices. The major components are identified and include the impact limiters and cask body. Chapter 1 Appendix 1.3.3 also provides a general bill of materials for the package and its components. In addition, the main package weights, dimensions, and thicknesses are summarized in the tables in Appendix 1.3.2 of Chapter 1.

Package shielding is mainly provided by the following features:

- Cask side wall that contains lead and stainless-steel
- Stainless-steel from cask rear forging
- Stainless-steel from the lid

2.1.1. Discussion

The RT-200 cask body is a cylindrical container whose main dimensions are summarized by Tables in Appendix 1.3.2 of Chapter 1. The sidewalls consist of a lead layer encased by internal and external stainless-steel shells, have a ceramic insulation layer, and have an outer protective stainless-steel shell. The cask sidewall design varies from the above description in the following areas:

- Regions of the cask body encompassed by the impact limiters
- Lifting trunnion locations
- Tie-down trunnion locations

The specific sidewall configuration at each of these locations is further described and fully considered in all subsequent evaluations.

[redacted]

[redacted]

The lid has thirty (30) clearance holes near its outer periphery for the M42 stainless-steel bolts, which secure it to the bolting ring. These clearance holes are sufficiently counter-bored to preclude direct impact to the M42 bolts during a drop.

The impact limiters are cylindrically shaped components that surround the front and rear ends of the cask as shown in Chapter 1. The impact limiters are bolted to the lid or the rear of the cask with eight (8) equally spaced M42 bolts. The impact limiters are comprised of rigid foam encased in relatively thin stainless-steel outer coverings. During NCT and HAC drops, the impact limiters are designed to protect the cask by absorbing impact energy and for providing thermal insulation.

As shown in Chapter 4, Section 4.1, the containment boundary of the RT-200 cask is defined by the following specific features of the cask body and lid.

- Rear forging at the rear of the cask

[redacted]

- Front forging at the front of the cask

[redacted]

- Lid and its inner O-ring
- Vent/Drain port cover plates and their inner O-rings

2.1.2. Design Criteria

The RT-200 design satisfies the NCT requirements of 10 CFR 71.71 [Ref. 10], and HAC requirements of 10 CFR 71.73 [Ref. 10]. Furthermore, the design complies with “General Standards for All Packages” as specified in 10 CFR 71.43 [Ref. 10], and the “Lifting and Tie- Down Standards” specified in 10 CFR 71.45 [Ref. 10].

The RT-200 cask is designed in accordance with both the ASME Code [Ref. 13] and RG 7.6 [Ref. 14] which develops the design criteria “acceptable to the NRC staff for use in the structural analysis of the containment vessels of Type B packages”. The criteria presented in RG 7.6 [Ref. 14] are specifically developed for linear structural analyses. When numerical analyses consider non-linear behavior of the materials, these criteria are not adapted, and are instead derived from the ASME recommendations for non-linear analyses (e.g. RT-200 cask body analyses).

For normal conditions of transport, the ASME [Ref. 13] criteria are the same as those of RG 7.6 [Ref. 14]. For accidental conditions, the ASME Code specifies various sets of criteria among which some are to be used for linear analyses and some for plastic analyses. The plastic analyses criteria are presented in ASME, Section III Appendices, Mandatory Appendix XXVII as stated in ASME, Section III, Division 3, WB-3224.2.

Each allowable stress intensity is a multiple of the ASME Code [Ref. 13] appropriate Stress Intensity value. The stress intensity values are presented in Table 2.12-1 of 2.12.2.

2.1.2.1. Cask Body Criteria

The criteria for the cask shells and forgings are summarized in Table 2.1-1 (the trunnions are also fabricated from stainless steel, but their criteria are developed separately in Section 2.5). These criteria are to be used in conjunction with the load combinations described in Table 2.6-2 and in Table 2.7-2.

Table 2.1-1 Structural Design Criteria for RT-200 Cask Body

<table>
<tr><th colspan="2" rowspan="2">STRESS CATEGORY</th><th colspan="2">STRESS CRITERIA</th></tr>
<tr><th>Normal Conditions of Transport (ASME Service Level A)</th><th>Hypothetical Accident Conditions (ASME Service Level D)</th></tr>
<tr><td rowspan="2">Primary Membrane</td><td>General P_m</td><td>S_m
(1)</td><td rowspan="2">$\text{Max}\left(S_y + \frac{1}{3}(S_u - S_y), 0.7\ S_u\right)$
(4)</td></tr>
<tr><td>Local P_l (2)</td><td>$1.5\ S_m$
(2)</td></tr>
<tr><td>Primary Membrane + Bending</td><td>$(P_m \text{ or } P_l) + P_b$</td><td>$1.5\ S_m$
(1)</td><td>$0.9\ S_u$
(5)</td></tr>
<tr><td>Primary + Secondary</td><td>$(P_m \text{ or } P_l) + P_b + Q$</td><td>$3.0\ S_m$
(3)</td><td>$2\ \times S_a$ for 10 cycles
(6)</td></tr>
</table>

Notes:

1. RG 7.6 [Ref. 14], Regulatory Position 2
2. The local primary membrane stress has the characteristics of a secondary stress. It is self-limiting as local yielding can alleviate the conditions that cause the stress to occur. The local primary membrane stress limit for normal conditions is taken directly from Code Article WB-3200 [Ref. 13].
3. RG 7.6 [Ref. 14], Regulatory Position 4
4. ASME Code [Ref. 13], III, Appendix XXVII-3311
5. ASME Code [Ref. 13], III, Appendix XXVII-3312
6. RG 7.6 [Ref. 14], Regulatory Position 7

The various parameters used in setting the criteria are defined as follows:

P_m or P_l	=	Primary general membrane stress or primary local membrane stress
P_b	=	Primary bending stress
Q	=	Secondary stress
S_m	=	Material's design stress intensity
S_u	=	Material's tensile strength
S_y	=	Material's yield strength
S_a	=	Material's adjusted fatigue stress limit at 10 cycles (adjusted to account for elasticity modulus)

2.1.2.2. Bolts Criteria

The three acceptance criteria used in this calculation are stated in Tables 6.1, 6.2 and 6.3 of NUREG/CR-6007 [Ref. 15]. They are developed based on analysis conditions which refer to the normal and hypothetical accident conditions of the 10 CFR 71 Regulation [Ref. 10]:

(1) The maximum stress analysis of normal conditions

(2) The fatigue stress analysis of normal conditions

(3) The maximum stress analysis of accident conditions

They are detailed hereafter.

(1) The limits on bolt stresses under NCT (Table 6.1 of NUREG/CR-6007 [Ref. 15]) are:

Using Sm as the basic allowable stress limit for the bolt material:

$$Sm = \frac{2}{3} \times Sy$$

Where Sy is the minimum yield stress or strength of the bolt material at the room temperature or at the operation temperature, whichever is less.

Tension:

$$f_t < Sm$$

Shear:

$$f_s < 0.6\,Sm$$

Tension plus shear:

$$\left(\frac{f_t}{Sm}\right)^2 + \left(\frac{f_s}{0.6\,Sm}\right)^2 < 1.0$$

Tension plus shear plus residual torsion:

$$S_{bi} < 1.35\,Sm$$

where

f_t	=	average tensile stress
f_s	=	average shear stress
S_{bi}	=	maximum stress intensity

(2) The acceptance criteria on bolt stresses for the fatigue analysis under NCT (Table 6.2 of NUREG/CR-6007 [Ref. 15]) are:

Using U as the cumulative usage factor:

$$U = \frac{n}{N} < 1.0$$

where

n	=	assumed number of cycles during lifetime
N	=	maximum allowable number of cycles, determined from the fatigue curves I-9.4 of the ASME Code, Section III, Appendix I [Ref. 13]

(3) The limits on bolt stresses under HAC (Table 6.3 of NUREG/CR-6007 [Ref. 15]) are:

Using Sy as the minimum yield strength of the bolt material and Su as the minimum ultimate strength of the bolt material:

Tension:

$$f_t < Min(0.7Su, Sy)$$

Shear:

$$f_s < Min(0.42Su, 0.6Sy)$$

Tension plus shear:

$$\left(\frac{f_t}{Min(0.7Su, Sy)}\right)^2 + \left(\frac{f_s}{Min(0.42Su, 0.6Sy)}\right)^2 < 1.0$$

where

$f_t =$ average tensile stress

$f_s =$ average shear stress

2.1.2.3. Lead

The structural integrity of the RT-200 cask does not depend on lead strength and thus, no lead strength criterion is specified. Mechanical and thermal properties which are important to the RT-200 cask structural performance are presented in Section 2.2.

2.1.2.4. Other Structural Failure Modes

Any structural element subjected to a cyclic loading during RT-200 cask's life cycle is evaluated for fatigue. Validation criteria for fatigue resistance are established from the design fatigue curves in Appendix I of Section III of the ASME Code [Ref. 13], as specified in Regulatory Position 3 of RG 7.6 [Ref. 14].

The buckling stability evaluation of the RT-200 cask body is included in the structural analyses since they include inelastic behavior of the materials.

2.1.3. Weights and Centers of Gravity

The nominal RT-200 weights and centers of gravity are shown in the tables of Appendix 1.3.2 (Chapter 1). Refer to the RT-200 bill of materials and assembly drawings in Appendices 1.3.3 and 1.3.4 of Chapter 1 for identification of assemblies and centers of gravity data. These weights are utilized in the structural evaluation presented in this chapter. All analyses are performed with a gross weight of 76,500 kg.

2.1.4. Identification of Codes and Standards for Package Design

Since the package is used to transport contents with a maximum of 3,000 A_2 and 30,000 Ci (as defined in Section 1.2.2 of Chapter 1), the RT-200 cask is a Type B Category II package per Regulatory Guide 7.11 [Ref. 16]. The codes and standards used in the design of the RT-200 cask are selected based on guidance provided in the ASME Code [Ref. 13], Regulatory Guide 7.6 [Ref. 14] and NUREG/CR-3854 [Ref. 17] for packages transporting Category II contents.

Per Table 4.1 of NUREG/CR-3854 [Ref. 17], the package containment system is fabricated in accordance with the ASME Code, Section III, Subsection NCD [Ref. 13], and the other systems (non-containment components) are fabricated in accordance with Subsection NF [Ref. 13]. These codes are applicable to the RT-200 cask design as they were developed for components of similar material as well as for similar loading operations and failure modes.

Several regulatory guides and NUREGs are used to design and evaluate the RT-200 package. Regulatory Guide 7.8 [Ref. 18] is used in identifying the load combinations to be used in package design evaluation. Regulatory Guide 7.6 [Ref. 14], in conjunction with the ASME Code [Ref. 13], is used to determine the design criteria. NUREG/CR-6007 [Ref. 15] is followed for the bolt evaluations.

2.2. MATERIALS

Material mechanical properties used in the RT-200 cask structural analyses are shown in the tables of Appendix 2.12.2.

2.2.1. Material Properties and Specifications

All structural components of the cask body and bolts are made of stainless-steel. Details are shown by the general bill of material provided in Appendix 1.3.3 of Chapter 1. Stainless-steel materials meet the requirements of ASME Section III [Ref. 13] (Subsections NCD or NF). Metallic materials strength properties are presented in Table 2.12-1 in Appendix 2.12.2 using material information taken from ASME Section II [Ref. 13]. Table 2.12-2 provides their density and Poisson's ratio values also from ASME Section II.

The primary material used for shielding is lead. The lead properties are provided in NUREG/CR-0481 [Ref. 19] and are presented in Table 2.12-1.

In accordance with Section 4.1.2 of Chapter 4, all seals used as part of the containment boundary are elastomer O-rings. They serve as one of the boundaries for the cask. These O-rings have a working temperature range from -45°C to 150°C (see Section 3.2.2 of Chapter 3); this temperature range meets or exceeds both NCT and HAC requirements.

Allowable stresses based on the ASME Code and Regulatory Guide 7.6 [Ref. 14] at the bounding NCT temperature of 80°C are provided in Table 2.2-1. Allowable stress intensities at other temperatures considered to be the bounding conditions for specific cases are defined as needed in the sections where the analyses are presented.

All the force-deformation properties for impact limiters are based on appropriate test conditions and temperature. Test parameters for qualifying the foam material are identified in Chapter 2, Appendix 2.12.2, Table 2.12-3. These parameters are used for defining the bounding curves of the foam's mechanical behavior, which are considered as input data for the structural evaluation. The method used to derive the parameters is presented in detail in RT-200 NTE 2001 [Ref. 27] and is derived from the manufacturer's recommendations.

Table 2.2-1 Allowable Stresses for Cask Body Materials

Transport Condition	Material and Cask Body Component	Design Stress Intensity Sm *(MPa)*	Tensile Strength Su *(MPa)*	10 Cycles Fatigue Stress Limit Sa *(MPa)*	Stress State	Allowable Stress (1) *(MPa)*
NCT	*Inner & Outer Shells*	115.0	462.3	3,682.2	P_m	115.0
					P_l	172.5
					$P_m + P_b$	172.5
					$P_m + P_b + Q$	345.0
	Bottom & Top Forgings, Closure Lid	115.0	428.6	3,682.2	P_m	115.0
					P_l	172.5
					$P_m + P_b$	172.5
					$P_m + P_b + Q$	345.0
HAC	*Inner & Outer Shells*	115.0	462.3	3,682.2	P_m	453.1
					P_l	453.1
					$P_m + P_b$	582.5
					$P_m + P_b + Q$	7364.3 *1841* (2)
	Bottom & Top Forgings, Closure Lid	115.0	428.6	3,682.2	P_m	390.0
					P_l	390.0
					$P_m + P_b$	501.5
					$P_m + P_b + Q$	7364.3 *1841* (2)

Notes:

1. The criteria used in the accidental conditions are converted into true values for direct comparison with the numerical results. Details regarding this topic are given in [Ref. 26].
2. As explained in Regulatory Guide 7.6, position 7 [Ref. 14], appropriate stress concentration factors for structural discontinuities should be used. In the cask body calculations, a value of 4 is used. The allowable stress to use in locations of structural discontinuities is marked in italic.

2.2.2. Chemical, Galvanic, or Other Reactions

The materials used in the fabrication and operation of the RT-200, including coatings, lubricants, and cleaning agents, are evaluated to determine whether chemical, galvanic, or other reactions among the materials, contents, and environments can occur. All phases of operation, loading, unloading, handling, storage, and transportation are considered (in conjunction with the procedures described in Chapter 7) for the environments that may be encountered under normal, off-normal, or accident conditions. Based on the evaluation, there are no potential reactions that could adversely affect the overall integrity of the cask or the structural integrity and retrievability of the contents from the cask. The evaluation demonstrates that the RT-200 cask meets the requirements of 10 CFR 71.43(d) [Ref. 10].

2.2.2.1. Component material categories

The component materials evaluated are categorized based on similarity of physical and chemical properties and/or on similarity of component functions. The categories of materials that are considered are as follows:

- Stainless/nickel alloy steels
- Nonferrous metals
- Shielding materials
- Critically control materials
- Energy absorbing materials
- Cellular foam and insulation
- Lubricants and grease
- O-rings
- Secondary containers and Shoring

These categories are evaluated based on the environment to which they could be exposed during operation or use of the RT-200.

The RT-200 component materials are not reactive among themselves, with the cask's contents, nor with the cask's operating environments during any phase of normal, or accident condition loading, unloading, handling, storage or transportation operations. No reactions occur, and no gases or other corrosion byproducts are generated.

2.2.2.1.1. Stainless/Nickel Alloy Steels

No reaction of the cask components (stainless or nickel alloy) is expected in any environment. During the fabrication process of the RT-200 ridges and crevices on the external surfaces are reduced through the finishing process and the external surface is passivated to prevent corrosion.

Galvanic corrosion between the stainless-steels and nickel alloy steels does not occur due to the lack of effective electrochemical potential difference between these metals. No coatings are applied to the stainless-steel or nickel alloy steels.

There is no potential for a reaction between stainless-steel and any silicone products, fluorocarbon elastomers, dry film lubricants, blended polytetrafluoroethylene (PTFE), or ethylene glycol.

Based on the foregoing discussion, there are no potential reactions expected with the stainless-steel cask components.

2.2.2.1.2. Nonferrous Metals

There are no nonferrous metals used in the RT-200. Therefore, no electrochemical driving potential exists.

2.2.2.1.3. Shielding Material

The primary shielding material used in the RT-200 is lead which is completely enclosed and sealed in stainless-steel. Therefore, there are no potential reactions associated with the cask shielding materials.

2.2.2.1.4. Criticality Control Material

The RT-200 does not contain materials for criticality control. Therefore, no potential reactions associated with these materials exist.

2.2.2.1.5. Energy Absorbing Material

The RT-200 utilizes polymer foam for energy absorption in the impact limiters. The foam is completely enclosed (sealed) in stainless-steel and there are no potential reactions between the foam and the stainless-steel shells. [redacted] Therefore, no potential reactions associated with the energy absorbing material exists.

2.2.2.1.6. Cellular Foam and Insulation

The RT-200 utilizes ceramic fiber paper for thermal insulation. This paper is completely enclosed (sealed) in stainless-steel and there are no potential reactions between the paper and the stainless-steel shells. Therefore, no potential reactions associated with the insulation material exists.

2.2.2.1.7. Lubricant and Grease

The dry film lubricants used with the RT-200 meet the performance and general compositional requirements of the nuclear power industry. These lubricants are used primarily on threaded/mechanical connection surfaces. These lubricants are insoluble in most solutions. There are no potential reactions associated with these lubricants or grease.

2.2.2.1.8. O-Rings

The RT-200 utilizes seals formed from EPDM. EPDM is a synthetic rubber elastomer. Elastomer O-rings are used for transport cask applications because of their excellent short-term sealing capabilities, ease of handling, and more economical cost. Seal and gasket materials have stable, non-reactive compositions. There are no potential reactions associated with the RT-200 seal materials.

2.2.2.1.9. Secondary Containers and Shoring

Secondary containers and shoring features may be constructed of carbon steel, stainless-steel, wood, or a thermoplastic such as polyethylene or polypropylene. There are no potential reactions associated with these materials.

2.2.2.2. General Effects of Identified Reactions

No significant potential galvanic or other reactions have been identified for the RT-200. Therefore, no adverse conditions can result during any phase of cask operations for NCT or HAC.

2.2.2.3. Adequacy of the Cask Operating Procedures

Based on the results of this evaluation, it is concluded that the RT-200 operating controls and procedures presented in Chapter 7 are adequate to minimize occurrence of hazardous conditions.

2.2.2.4. Effects on Reactions Byproducts

No significant potential chemical, galvanic, or other reactions are identified for the RT-200. Therefore, the overall integrity of the cask and the structural integrity and retrievability of the contents will not be adversely affected for any cask operations throughout the design basis life of the cask. Based on the evaluation, no significant reactions are identified and thus, there is no change in cask properties, no binding of mechanical surface, and no degradation of any safety components either directly or indirectly.

2.2.3. Effects of Radiations on Materials

Gamma radiation has no significant effect on metal and therefore, the radiation produced by the contained radioactivity does not cause any measurable damage to the cask metallic components (stainless-steel and lead).

For the seals, the potential dose absorbed in a year is significantly below the limit provided in the support information for EPDM's resistance to radiation up to $5 \cdot 10^8$ rads (see Appendix 4.6.5) while retaining reasonable flexibility and strength, hardness and very good compression. The amount of time needed to achieve the cumulated dose limit far exceeds the time schedule for seal replacement.

Ceramic materials are insensitive to gamma radiation damage and thus, the ceramic thermal shield is expected to be unaffected by radiation.

2.3. FABRICATION AND EXAMINATION

The following subsections provide a summary description of fabrication and examination of the RT-200. A more detailed description is provided in subsequent sections of the SAR.

2.3.1. Fabrication

The RT-200 packaging is designed as a category II container, as mentioned in Section 2.1.4. Fabrication and procurement of the containment components is based on ASME B&PV code, Section III, Subsection NCD – Class 3 [Ref. 13]. The other components (non-containment) are fabricated based on ASME B&PV code, Section III, Subsection NF [Ref. 13].

2.3.2. Examination

Examination of the RT-200 during and after fabrication is conducted in accordance with the requirements of the ASME B&PV code, Section III, Subsection NCD [Ref. 13]. The non-containment components examination is conducted in accordance with the requirements of ASME B&PV Code, Section III, Subsection NF [Ref. 13]. See Chapter 8, Sections 8.1 and 8.2 for additional information.

2.4. GENERAL REQUIREMENTS FOR ALL PACKAGES

The RT-200 meets or exceeds all the requirements in 10 CFR 71.43 [Ref. 10]. The following sections describe compliance of the RT-200 with these requirements.

2.4.1. Minimum Package Size

This section is not applicable since the RT-200 has dimensions larger than 10 cm (4 inches) in accordance with 10 CFR 71.43(a) [Ref. 10]. The smallest overall dimension of the cask body is the outer diameter, which is over 150 cm.

2.4.2. Tamper-Indicating Feature

The RT-200's front impact limiter covers the front end of the cask, which prevents access to the cask lid.

Therefore, tamper-indicating devices are attached to the impact limiter bolts. Impact limiters are installed on the lid and rear end of the cask body following the lid closure operation. Once the impact limiters are installed, attachment nuts are inserted in the attaching bolts heads. A rotation lock part is bolted in the nuts (two nuts for each lock part) and tightened with a threaded pin to the impact limiter. Eventually, a tamper-indicating seal is installed on the pin to assure that removal of the impact limiter by unauthorized individuals can be detected in accordance with 10 CFR 71.43(b) [Ref. 10].

2.4.3. Positive Closure

The RT-200 design includes a containment system bounded by the inner shell, lid, and drain/vent port cover plates. The lid and the cover plates are secured to the cask body by multiple bolts. These bolts are tightened during the loading process to a set torque value that cannot be inadvertently loosened in accordance with 10 CFR 71.43(c) [Ref. 10]. Additionally, the stress analysis of the bolts presented in Section 2.6.7 demonstrates that the bolts maintain positive closure during operation.

The RT-200 does not rely on any valve or pressure relief device to meet the containment requirements. The quick disconnect valves on the vent and drain ports are protected by the cover plates which protect the valve from unauthorized operation and provide a sealed enclosure to retain any leakage from the device in accordance with 10 CFR 71.43(e) [Ref. 10].

2.5. Lifting and Tie-Down Standards for All Packages

The RT-200 lifting and tie-down components are structurally evaluated in the following sections. The lifting and tie-down requirements are specified in 10 CFR 71.45 [Ref. 10]. Additionally, when relevant, the lifting and tie-down devices are evaluated for fatigue, as described in Appendix 2.12.3, and as required per Regulatory Guide 7.8 [Ref. 18].

2.5.1. Lifting Devices

The primary lifting system for the RT-200 is composed of two components:

- One set of two lifting trunnions that are bolted to the front forging of the cask.
- One set of two supporting trunnions that are welded to the rear of the cask body.

Two cask body lifting cases can be considered. The first case occurs when the cask is in a vertical position, without the impact limiters. It can be lifted using the two top trunnions. The second case also occurs with the two impact limiters removed, when the cask is rotated from the horizontal to the vertical position (or conversely). In this case, the two top trunnions are hooked by a special lifting device or other approved rigging equipment and the two bottom trunnions are positioned on supports that allow the cask to rotate from the horizontal to the vertical position (or conversely). For both cases no other structural part of the package could be used for the cask lifting.

The lifting of the lid is performed using lifting rings. The lid is threaded with bolt holes, which are used for the attachment of the rings. The lifting rings are only used for lifting when the lid is detached from the cask body and are rendered inoperable by removing the rings from the lid when the cask is assembled.

The front/rear impact limiters are fitted with a lifting belt; this element allows the impact limiters to be lifted using standard lifting equipment. The welded lifting eyes, located on top of the impact limiters, are only used for angular stabilization of the impact limiter during lifting.

The disposable insert is fitted with a lifting eye on its upper surface, which is structurally integral to the disposable insert and allows the insert to be lifted using a special lifting device. The lifting eye is part of a vertical shell which contains, at its other end, 4 pins that are used as supports for the bottom plate and for the weight of the disposable insert's content.

The lifting of the basket is performed using lifting rings. The basket has threaded bolt holes, which are used for the attachment of the rings. The lifting rings are only used for lifting when the basket is being removed from or installed into the cask body and are rendered inoperable by removing the rings from the basket when the cask is assembled.

2.5.1.1. Lifting Design Criteria

Lifting attachments that are a structural part of the RT-200 cask are designed to be capable of lifting more than six times the cask weight without generating a combined shear stress or maximum tensile stress at any point in the device in excess of the corresponding minimum yield strength of the material of construction, as per 10 CFR 71.45 [Ref. 10] and ANSI N14.6 [Ref. 20]. They are also designed to be capable of lifting more than ten times that weight without exceeding the ultimate tensile strength of the materials [Ref. 20]. These factors account for a design factor of two to meet critical load lifting requirements in accordance with [Ref. 20]. It is conservatively analyzed using a bounding temperature of +80°C for the material mechanical properties to cover the maximum temperature range that might be reached by the package under routine conditions of transport.

The lifting attachments are also designed so that any failure of the lifting attachment under excessive load would not impair the ability of the RT-200 to meet other requirements of 10 CFR 71 Subpart E [Ref. 10].

The design masses used in the lifting evaluation are the bounding masses listed in Appendix 1.3.2.

2.5.1.2. Lifting Attachment Evaluations

The capability of each lifting attachment to meet the structural requirements is analytically evaluated. Each evaluation is presented including the worst-case stress results and safety factors.

2.5.1.2.1. Cask Body Lifting Evaluation

The cask body lifting is evaluated for each of the two lifting load cases described in Section 2.5.1. The corresponding calculations are detailed in RT-200 NTE 2002 [Ref. 21]. Input data including locations and geometry of the lifting attachments as well as stress results and safety factors are presented hereunder.

The cask body lifting attachments are also evaluated for mechanical fatigue. Appendix 2.12.3 subsections 2.12.3.4 and 2.12.3.5 present the fatigue analyses performed on the trunnions. These analyses demonstrate the capability of the cask body lifting attachments to resist the cyclic loads generated by lifting operations.

The overall geometry of the RT-200 packaging is detailed in the assembly drawing in Appendix 1.3.4 of Chapter 1. Its main dimensions, useful in the lifting evaluation, are:

- Cask body length: .... 5,250 mm
- Cask body diameter: .... 1,590 mm
- Position of the cask CoG: .... 2,600 mm (from the top of the front forging)

Figure 2.12-1 through Figure 2.12-3 of Appendix 2.12.4 present the lifting and supporting trunnions main geometric characteristics, which are considered in the analysis. Those figures are issued from the RT-200 assembly drawing in Appendix 1.3.4 of Chapter 1.

Table 2.5-1 hereunder summarizes the results of the cask body lifting evaluation for both load cases.

Table 2.5-1 Cask Body Lifting Evaluation – Results Summary

Design Load Case	**Lifting components**	**Loading:** $M_{max} \times g \times \gamma_Y \times \gamma_C$ $M_{max} \times g \times \gamma_U \times \gamma_C$	**Minimum Safety factor:** ***Requirement: ≥ 1***	
Load case 1: Vertical Lifting of the RT-200 cask without impact limiters	Top trunnions	$\gamma_Y = 3\ and\ \gamma_C = 2$	Related to $Sy^{min}_{@+80°C}$:	**1.9**
		$\gamma_U = 5\ and\ \gamma_C = 2$	Related to $Su^{min}_{@+80°C}$:	**1.7**
	Top trunnions M42 Fixing bolts	$\gamma_Y = 3\ and\ \gamma_C = 2$	*Tensile stress in the bolt*: Related to $Sy^{min}_{@+80°C}$:	**5.1**
		$\gamma_U = 5\ and\ \gamma_C = 2$	*Tensile stress in the bolt*: Related to $Su^{min}_{@+80°C}$:	**4.7**
		$\gamma_Y = 3\ and\ \gamma_C = 2$	*Tearing of the bolt*: Related to $Sy^{min}_{@+80°C}$:	**7.8**
		$\gamma_U = 5\ and\ \gamma_C = 2$	*Tearing of the bolt*: Related to $Su^{min}_{@+80°C}$:	**13.2**
Load case 2(1): Rotation of the RT-200 cask without impact limiters (horizontal to vertical & conversely)	Bottom trunnions	$\gamma_Y = 3\ and\ \gamma_C = 2$	Related to $Sy^{min}_{@+80°C}$:	**3.2**
		$\gamma_U = 5\ and\ \gamma_C = 2$	Related to $Su^{min}_{@+80°C}$:	**5.4**
	Welds of the bottom trunnions	$\gamma_Y = 3\ and\ \gamma_C = 2$	Related to $Sy^{min}_{@+80°C}$:	**1.3**
		$\gamma_U = 5\ and\ \gamma_C = 2$	Related to $Su^{min}_{@+80°C}$:	**2.2**

Notes:

(1) Top trunnions are not considered in the load case 2 since case 1 generates a more penalizing loading condition on each trunnion;

These results show that:

- in the event of the load case 1, the top trunnions of the RT-200 meet the requirements described in Section 2.5.1.1 relative to both regulations [Ref. 10] and standard [Ref. 20] : a minimum safety factor of 1.7 is ensured;
- in the event of the load case 2, the bottom trunnions of the RT-200 meet the requirements described in section 2.5.1.1 relative to both [Ref. 10] regulations and [Ref. 20] standard: minimum safety factor of 1.3 is ensured.

The RT-200 cask handling trunnions therefore meet all regulatory requirements.

2.5.1.2.2. Lid Lifting Evaluation

This subsection presents the evaluation of the lid for the working load limit in the lifting rings and for the tear-out stresses in the lid from the lifting activities.

The lid's lifting attachments are also evaluated for mechanical fatigue. Appendix 2.12.3, section 2.12.3.3 presents the fatigue analysis performed on the lid's threads. The latter are used for both the lid lifting during cask handling and the impact limiter fixation during transport. Thus, both of these conditions are considered in the fatigue analysis. The latter analysis demonstrates the capability of the lid's threads to resist the cyclic loads generated by lifting and transport operations. Additionally, the operations involving the lifting and handling of the cask lid are performed inside the nuclear power plant and are considered critical in the evaluations; it is therefore analyzed with a critical load factor of 2.

The design information regarding the lid lifting is:

Closure Lid Mass	M_{Lid}	=	3,075 kg, assume 3,200 kg
Number of Lifting Rings	n_r	=	4
Critical Load Factor	Γ_{crit}	=	2

2.5.1.2.2.1. Closure Lid Lifting Ring Working Loads

The lifting rings are only used for lifting when the lid is detached from the cask body and are rendered inoperable by removing the rings from the lid when the cask is assembled. The rings are therefore not considered to be a structural part of the package and do not need to be designed for the factor of safety against yielding. Conservatively, a factor of safety of three is also considered to define the minimum ring working load limit.

Lifting Ring Load	W_{lr}	=	$\frac{M_{lid} \times \Gamma_{crit}}{n_r}$	=	1,600 kg
Ring Working Load Limit	$W_{lr.min}$	=	5,000 kg		
Factor of Safety	FS_{lr}	=	$\frac{W_{lr.min}}{W_{lr}}$	=	3.1 > 3.0

2.5.1.2.2.2. Closure Lid Metal Tear-Out Stresses

The minimum required thread engagement length is determined in accordance with the "Formulas for Stress Areas and Lengths of Engagement of Screw Threads" of the "Machinery's Handbook 27th Edition" [Ref. 22]. The length of engagement of mating threads should be sufficient to carry the full load necessary to break the screw without the thread stripping. If mating internal and external threads are made of materials having equal tensile strengths, its value should be not less than that given by:

$$L_e = \frac{2A_t}{\pi K_{n.max}(\frac{1}{2} + 0.57735n(E_{s.min} - K_{n.max}))}$$

Where,

A_t	=	tensile-stress area of the screw thread (for steels over 100,000 psi tensile strength)
n	=	0.2/mm, number of threads per mm
$K_{n.max}$	=	37.799 mm, Maximum minor diameter of internal thread for M42 thread (1)
$E_{s.min}$	=	38.778 mm, Minimum pitch diameter of external thread for M42 thread (2)

Notes:

(1) Information extracted from section "METRIC SCREW THREADS M PROFILE", Table 12 "Internal Metric Thread – M Profile Limiting Dimensions", of the Machinery's Handbook 27th Edition [Ref. 22].

(2) Information extracted from section "METRIC SCREW THREADS M PROFILE", Table 13 "External Metric Thread – M Profile Limiting Dimensions" of the Machinery's Handbook 27th Edition [Ref. 22].

The tensile-stress area of the screw thread, for steels over 100,000 psi tensile strength, equals:

$$A_t = \pi \left(\frac{E_{s.min}}{2} - \frac{0.16238}{n} \right)^2 = 1{,}094\ mm^2$$

Thus, the minimum length engagement (if materials with same tensile strengths are used for internal and external threads) is:

$$L_e = 29.4\ mm$$

Stripping of the internal thread may occur before the screw breaks. To determine whether this condition exists, the factor J for the relative strength of the external and internal threads is calculated as:

$$J = \frac{k_{ring} \times W_{lr} \times g}{A_n \times S_{ul}}$$

Where,

S_{ul} = 428.6 MPa, tensile strength of the lid's material at 80°C
A_n = shear area of the lid's threaded hole
k_{ring} = 5, safety coefficient before break according to common values for lifting rings

J is evaluated using a modified form of the formula from [Ref. 22]. The numerator corresponds to the tensile load that leads to the bolt break. It is calculated using the lifting ring safety coefficient before break, which is a data given by the lifting ring's supplier.

The shear areas of the external and internal threads, respectively, are calculated as follows:

$$A_n = \pi\, n\, L_e D_{s.min} \left[\frac{1}{2n} + 0.57735 (D_{s.min} - E_{n.\max}) \right]$$

Where,

$D_{s.min}$ = 41.437 mm, Minimum major diameter of external thread for M42 threads (1)
$E_{n.max}$ = 39.392 mm, Maximum pitch diameter of internal thread for M42 threads (2)
All other terms are as previously described.

Notes:

(1) Information extracted from section “METRIC SCREW THREADS M PROFILE”, Table 13 “External Metric Thread – M Profile Limiting Dimensions”, of the Machinery’s Handbook 27th Edition [Ref. 22].

(2) Information extracted from section “METRIC SCREW THREADS M PROFILE”, Table 12 “Internal Metric Thread – M Profile Limiting Dimensions” of the Machinery’s Handbook 27th Edition [Ref. 22].

Thus, the factor J for the relative strength of the external and internal threads equals:

$$J = 0.1$$

Since $J < 1$, the required length of engagement Q to prevent stripping of the internal thread is the previously calculated length of engagement L_e :

$$Q = L_e = 29.4\ mm$$

The available thread engagement length between the lifting ring and the lid’s threaded hole is 69 mm and is therefore superior to the required length of engagement to prevent stripping of the lid’s thread.

The lifting ring configuration is therefore acceptable for the applied loads.

2.5.1.2.3. Impact Limiter Lifting Evaluation

The impact limiters are lifted using two devices: a surrounding belt fitted with a lifting eye on each extremity and a pair of lifting eyes. Although the surrounding belt is the principal lifting attachment, it is used in conjunction with the pair of welded lifting eyes to suppress any rotation that would occur during lifting. The operations involving the lifting and handling of the impact limiters are performed inside the nuclear power plant and are considered critical in the evaluations; they are therefore analyzed with a critical load factor of 2.

Figure 2.12-4 of Appendix 2.12.4 shows a drawing of the impact limiter’s lifting attachment, with the various dimensions used in the following calculations. The belt is bolted on the outer shell and is evaluated for the maximal mass of the impact limiters. The impact limiter lifting can only be performed when the impact limiter is no longer bolted to the cask.

In addition to the evaluations presented in the following subsections, which demonstrate the capability of the impact limiter’s lifting attachment to meet the design criteria described in section 2.5.1.1, the impact limiter’s lifting attachment is also evaluated for mechanical fatigue. Appendix 2.12.3 Section 2.12.3.6 presents the fatigue analysis performed on the lifting belt. This analysis demonstrates the capability of the impact limiter’s lifting attachment to resist the cyclic loads generated by lifting operations.

An illustration of the lifting belt’s eye with its main dimensions used in the calculation is shown in Figure 2.12-4 of Appendix 2.12.4.

The impact limiter lifting belt is evaluated relatively to both yielding and tensile strengths. Thus, two maximal axial loadings are calculated for each extremity of the lifting belt:

$$\begin{cases} F_{IL.y} = \dfrac{M_{IL} \times g \times \Gamma_{\mathrm{y}} \times \Gamma_{\mathrm{crit}}}{2} \times \dfrac{1}{\cos{(\alpha)}} \\ F_{IL.u} = \dfrac{M_{IL} \times g \times \Gamma_{\mathrm{u}} \times \Gamma_{\mathrm{crit}}}{2} \times \dfrac{1}{\cos{(\alpha)}} \end{cases}$$

Where,

M_{IL}	=	$3{,}750\ \mathrm{kg}$,	bounding mass of one impact limiter
g	=	$9.81\ \mathrm{m/s2}$,	gravity acceleration
Γ_{y}	=	3,	stress design factor relative to tensile yield strength
Γ_{u}	=	5,	stress design factor relative to ultimate tensile strength
Γ_{crit}	=	2,	critical load factor
α	=	30°,	angle between the lifting eye and the vertical

Thus,

$$\begin{cases} F_{IL.y} = 127.4\ kN \\ F_{IL.u} = 212.4\ kN \end{cases}$$

These maximal axial loads are used to calculate the tensile stress at the base of the lifting belt's eye:

$$\sigma_{nom} = \frac{F_{IL}}{S_h}$$

Where,

S_h	=	$T_h(D - 2 \times R_h)$	
	=	1,800 mm^2,	horizontal surface at the base of the eye
D	=	$2L_h + 2R_h$	
	=	250 mm,	width of the lifting belt
L_h	=	90 mm,	minimal length between the circle and the side of the belt
R_h	=	35 mm,	radius at the lower circle of the eye
T_h	=	10 mm,	thickness of the lifting belt
F_{IL}	=	$F_{IL.y}$ or $F_{IL.u}$	

Thus,

$$\begin{cases} \sigma_{nom.y} = 70.8\ MPa \\ \sigma_{nom.u} = 118.0\ MPa \end{cases}$$

According to Table 17 of "Roark's Formulas for Stress & Strain (7th Edition 1989)" [Ref. 23], the stress concentration factor for the lifting belt's eye equals:

$$K_t = 3 - 3.13\frac{2R_v}{D} + 3.66\left(\frac{2R_v}{D}\right)^2 - 1.53\left(\frac{2R_v}{D}\right)^3 = 2.1$$

Where,

R_v = 25 mm, radius at the upper circle of the eye
All other terms are as previously defined.

Using K_t, the maximum tensile stress on the lifting belt's eye is given as:

$$\sigma_{max} = K_t \times \sigma_{nom} = \begin{cases} \sigma_{max.y} = 148.4\ MPa \\ \sigma_{max.u} = 247.3\ MPa \end{cases}$$

Eventually, the safety factors on both the yield and the ultimate tensile stresses are determined:

$$\begin{cases} FS_{IL.belt.y} = \dfrac{S_{y.lb}}{\sigma_{max.y}} = 1.0^{*} \\ FS_{IL.belt.u} = \dfrac{S_{u.lb}}{\sigma_{max.u}} = 1.9 \end{cases}$$

Where,

$S_{y.lb}$ = 152.3 MPa, yield strength of the lifting belt's material
$S_{u.lb}$ = 462.3 MPa, ultimate tensile strength of the lifting belt's material

Note: The factor of safety on the yield strength is 1.03.

Including the critical load factor, both safety factors exceed the regulatory lifting requirements on the impact limiters. Therefore, the impact limiter's lifting belt configuration is acceptable for the required loads.

2.5.1.2.4. <u>Disposable Insert Lifting Evaluation</u>

The lifting of the disposable insert is performed with two components:

- The lifting eye fitted on top of the insert,
- The four lifting pins that support the weight of the 3 storage containers at the bottom end of the disposable insert.

Both of these components are evaluated regarding the lifting design criteria presented in Section 2.5.1.1.

Since the disposable insert is only used once per transport operation, no fatigue analysis is required on its lifting device attachment points.

2.5.1.2.4.1. Disposable Insert Lifting Loads

The operations involving the lifting and handling of the empty insert are performed inside the nuclear power plant and are considered critical in the evaluations; they are therefore analyzed with a critical load factor of 2. Once the insert is loaded with the three storage containers, the cask is closed before being moved to the storage facility. The loaded disposable insert is only lifted at the disposal facility, where the lifting is not considered critical.

For the empty insert case, the axial loadings equal:

$$\begin{cases} F_{DIE.y} = M_{DIE} \times g \times \Gamma_y \times \Gamma_{\text{crit}} = 47.1\ kN \\ F_{DIE.u} = M_{DIE} \times g \times \Gamma_u \times \Gamma_{\text{crit}} = 78.5\ kN \end{cases}$$

Where,

M_{DIE} = 800 kg, mass of the empty disposable insert
All the other terms are as previously defined.

For the loaded insert case, the axial loadings equal:

$$\begin{cases} F_{DIL.y} = M_{DIL} \times g \times \Gamma_y = 173.6\ kN \\ F_{DIL.u} = M_{DIL} \times g \times \Gamma_u = 289.3\ kN \end{cases}$$

Where,

M_{DIL} = $M_{DIE} + 3M_{SC}$
M_{DIL} = 5,900 kg, mass of the loaded disposable insert
M_{SC} = 1,700 kg, mass of a storage container
All the other terms are as previously defined.

The axial loadings corresponding to the loaded insert case are bounding and are therefore the loadings used in the lifting evaluation.

2.5.1.2.4.2. Disposable Insert's Lifting Eye Evaluation

An illustration of the lifting eye with its main dimensions used in the calculation is shown in Figure 2.12-5 of Appendix 2.12.4.

The disposable insert's lifting is performed either with an empty insert, in which case a critical load factor of 2 is applied or with a fully loaded insert, in which case no critical load factor is applied (see 2.5.1.2.4.1).

Additionally, the disposable insert's lifting eye is evaluated relatively to both yielding and tensile strengths. Thus, two maximal axial loadings are calculated for each of the two cases.

The tensile stress at the lifting eye's median section equals:

$$\sigma_{nom} = \frac{F_{DI}}{S_h}$$

Where,

S_h	=	$2L_hT_h - 4\frac{C_{di}^2}{2}$	
	=	2,390 mm^2,	surface at the base of the eye
L_h	=	30.5 mm,	minimal length at the horizontal of the eye
T_h	=	40 mm,	thickness of the lifting eye
C_{di}	=	5 mm,	chamfer around the lifting eye
F_{DI}	=	$F_{DIL.y}$ or $F_{DIL.u}$	

Thus,

$$\begin{cases} \sigma_{nom.y} = 72.6\ MPa \\ \sigma_{nom.u} = 121.0\ MPa \end{cases}$$

According to Table 17 of "Roark's Formulas for Stress & Strain (7th Edition 1989)" [Ref. 23], the stress concentration factor for the lifting eye equals:

$$K_t = 3 - 3.13\frac{2a}{D} + 3.66\left(\frac{2a}{D}\right)^2 - 1.53\left(\frac{2a}{D}\right)^3 = 1.7$$

Where,

a	=	20 mm,	radius of the circle in the lifting eye
D	=	$2a + 2L_h$	
	=	101.0 mm,	width of the lifting eye

Using k_t, the maximum tensile stress on the lifting eye is given as:

$$\sigma_{max} = K_t \times \sigma_{nom} = \begin{cases} \sigma_{max.y} = 123.5\ MPa \\ \sigma_{max.u} = 205.9\ MPa \end{cases}$$

The safety factors on both the yield and the ultimate tensile stresses are determined:

$$\begin{cases} FS_{DI.le.y} = \dfrac{S_{y.le}}{\sigma_{max.y}} = 1.2 \\ FS_{DI.le.u} = \dfrac{S_{u.le}}{\sigma_{max.u}} = 2.2 \end{cases}$$

Where,

$S_{y.le}$	=	152.3 MPa,	yield strength of the lifting eye's material
$S_{u.le}$	=	462.3 MPa,	ultimate tensile strength of the lifting eye's material

Both safety factors give a sufficient margin towards regulatory lifting requirements on disposable insert. Therefore, the insert's lifting eye's configuration is acceptable for the required loads.

2.5.1.2.4.3. Disposable Insert's Lifting Pins Evaluation

The four lifting pins are located at the bottom end of the disposable insert. Placed through the vertical plates that are connected to the lifting eye, they support the weight of the content in the disposable insert. An illustration of the lifting pins with the main dimensions used in the calculation is shown in Figure 2.12-6 of Appendix 2.12.4.

Shear stress in each pin is calculated as follows:

$$\tau_{pin} = \frac{\frac{F_{DI}}{N_{pins}}}{S_{pin}} = \begin{cases} \tau_{pin.y} = 86.8\ MPa \\ \tau_{pin.u} = 144.6\ MPa \end{cases}$$

Where,

N_{pins} = 4, number of pins used to support disposable insert bottom end
S_{pin} = $b_{pin} \times h_{pin}$, shear section of one pin
= $50mm \times 10mm$
= 500 mm^2
All other terms are as previously defined.

Eventually, the safety factors on both the yield and the ultimate tensile stresses are determined:

$$\begin{cases} FS_{DI.pin.y} = \dfrac{S_{y.pin}}{\tau_{pin.y}} = 1.8 \\ FS_{DI.pin.u} = \dfrac{S_{u.pin}}{\tau_{pin.u}} = 3.2 \end{cases}$$

Where,

$S_{y.pin}$ = 152.3 MPa, yield strength of the lifting pin's material (stainless steel)
$S_{u.pin}$ = 462.3 MPa, ultimate tensile strength of the lifting pin's material (stainless steel)

Both safety factors give a sufficient margin towards regulatory lifting requirements on disposable insert. Therefore, the insert's lifting pin's configuration is acceptable for the required loads.

2.5.1.2.5. <u>Basket Lifting Evaluation</u>

The operations involving the lifting and handling of the basket may be performed inside the nuclear power plant and are considered critical in the evaluations; they are therefore analyzed with a critical load factor of 2. The basket, however, will only ever be handled when empty.

Normal transport operations do not involve lifting and handling of the basket. Therefore, no fatigue analysis is performed on its lifting attachment points.

The basket is evaluated for the working load limit in the lifting rings and for the tear-out stresses in the basket from the lifting activities. The design information regarding the basket lifting is:

Basket Mass M_{Basket} = 2,338 kg, assume 2,500 kg

Number of Lifting Rings	n_r	=	3		
Critical Load Factor	Γ_{crit}	=	2		

2.5.1.2.5.1. *Basket Lifting Ring Working Loads*

The lifting rings are only used for lifting when the basket is detached from the cask body and are rendered inoperable by removing the rings from the basket when the cask is assembled. The rings are therefore not considered to be a structural part of the package and do not need to be designed for the factor of safety against yielding. Conservatively, a factor of safety of three is also considered to define the minimum ring working load limit.

Lifting Ring Load	W_{lr}	=	$\frac{M_{basket} \times \Gamma_{crit}}{n_r}$	=	1,666.7 kg
Ring Working Load Limit	$W_{lr.max}$	=	5,000 kg		
Factor of Safety	FS_{lr}	=	$\frac{W_{lr.max}}{W_{lr}}$	=	3.0

2.5.1.2.5.2. *Basket Metal Tear-Out Stresses*

The tear-out stresses in the basket's threaded holes are evaluated with the same methodology as the one used for the lid's holes. Since the materials and dimensions involved in the mating internal and external threads between the basket and the lifting rings are the same as for the closure lid's lifting, the same calculations are performed using the ring load due to basket lifting. Thus, the required basket's thread engagement length is given by the calculation process of Section 2.5.1.2.2.2 and equals 29.4 mm.

The available thread engagement length between the lifting ring and the basket's threaded hole is 84mm and is superior to the required length of engagement to prevent stripping of the basket's thread. The lifting ring configuration is therefore acceptable for the applied loads.

2.5.2. Tie-Down Devices

The tie-down of the RT-200 cask is performed with the two pairs of trunnions welded at the front and at the rear of the cask body. During transport, the cask is placed on a special transport frame and supported on each of these four trunnions. The welded trunnions allow to securely position the cask, and to absorb the vertical, longitudinal and transversal forces required by 10 CFR 71.45 [Ref. 10].

The pair of lifting trunnions described in Section 2.5.1 and bolted on the top forging is the only attachment protruding from the cask that could possibly be used to tie down the cask. These trunnions are hidden by the front impact limiter during transport and are therefore rendered inoperable for tie-down.

During transport, as discussed in Section 2.6.5, the cask is subjected to vibrations that contribute to mechanical fatigue. Therefore, a fatigue analysis of the tie-down devices is presented in Appendix 2.12.3 Section 2.12.3.4. This fatigue analysis considers the vibration loads described in Section 2.6.5 and demonstrates the capability of the tie-down devices to resist the cyclic loads generated by transport.

2.5.2.1. Tie-Down Device Criteria

According to the requirements of 10 CFR 71.45(b) [Ref. 10], the stress generated by the load the cask is subjected to during tie-down must not be greater than the yield strength of the material. It is conservatively considered a bounding temperature of +80°C for the material mechanical properties to cover the maximum temperature range that might be reached by the package under routine conditions of transport.

The design masses used in the tie-down evaluation are the bounding masses listed in Appendix 1.3.2.

2.5.2.2. Tie-Down Device Evaluation

The cask tie-down's evaluation is detailed in RT-200 NTE 2003 [Ref. 24]. Input data including locations and construction of the tie-down devices as well as loadings, stress results, and safety factors are presented hereunder.

The four welded trunnions are a structural part of the package, and must withstand the following loads without impairing the safety of the cask, as required by 10 CFR 71.45 [Ref. 10]:

- Two (2) times the loaded weight of the cask in the vertical direction
- Ten (10) times the loaded weight of the cask in the direction of travel (longitudinal)
- Five (5) times the loaded weight of the cask transverse to the direction of travel

These loads are considered to act simultaneously on the cask and the tie-down arms :

- The 2 g vertical load is shared between the four trunnions (two front and two rear);
- The 10 g load component, applied in the direction of transport, is shared equally between the four trunnions (two front and two rear);
- The 5 g load component, which is transverse to the direction of travel, is shared between one front trunnion and one rear trunnion on the same side of the cask. The trunnion pedestal tie-down allows for some movement transverse to the direction of travel in such a way that the 5 g loading only results in a uniform compressive force applied to the trunnion base plate flange.

The overall geometry of the RT-200 packaging is detailed by the assembly drawing in Appendix 1.3.4 of Chapter 1. The main dimensions which are useful in the tie-down evaluation, are:

- Overall length:... 6,130 mm
- Overall diameter:.. 2,445 mm
- Cask body length: .... 5,250 mm
- Cask body diameter: .... 1,590 mm
- Position of the cask CoG: .... 2,600 mm (from the top of the front forging)

The illustration shown in Figure 2.12-3 of Appendix 2.12.4 presents the main features of the trunnions that are considered within the transport calculations.

Table 2.5-2 summarizes the results of the cask tie-down evaluation.

Table 2.5-2 Cask Tie-Down Evaluation – Results Summary

Design Load Case	Lifting components	Safety factor	
Tie down	Transport trunnions	*Bending of the trunnion*: $Sy^{min}_{@+80°C}$ / σ_{eqv}^{max} = 152 MPa /80 MPa	**1.9**
		Compression of the base of the trunnion: $Sy^{min}_{@+80°C}$ / σ_{eqv}^{max} = 152 MPa /116 MPa	**1.3**
		Tearing and tensile stress in the weld: $Sy^{min}_{@+80°C}$ / σ_{weld}^{max} = 152 MPa /120 MPa	**1.3**

These results show that the RT-200 trunnions used for the retention of the package on the conveyance during transports comply with the requirements of the 10 CFR 71.45 [Ref. 10].

RT-200 package tie-down devices are safe and meet the regulation's requirements related to retention capability during transports. No failure can occur and the ability of the package to ensure its other safety functions cannot be impaired.

2.6. Normal Conditions of Transport

This section describes the RT-200's evaluation for the normal conditions of transport specified in 10 CFR 71.71 [Ref. 10]. The requirements of 10 CFR 71.71 state that the RT-200 shall be structurally adequate for the normal conditions of transport, which are addressed in the following subsections:

- heat
- cold
- reduced external pressure
- increased external pressure
- vibration
- water spray
- free drop
- corner drop
- compression
- penetration

Detailed structural analyses are provided among the references to this chapter. The most penalizing results are used in this chapter to demonstrate the capability of the RT-200 cask's design to meet the regulatory requirements in the context of the normal conditions of transport load combinations specified in 10 CFR 71 [Ref. 10] and Regulatory Guide 7.8 [Ref. 18].

The free drop analyses are performed in two steps. The first step consists in the calculation of the crushing forces and g-loads the cask is subjected to (RT-200 NTE 2101, Drops Calculations [Ref. 25]). As an example, Appendix 2.12.6, Section 2.12.6.1 provides details about the general method as well as the formulas used to specifically evaluate the 9-meter end-drop. The same method has been followed for the evaluations of all the other drop cases and the latter are presented in detail in [Ref. 25]. In the second step, the calculated forces and loads are used as inputs to numerical simulations to determine the stress intensities in the cask body (RT-200 NTE 2004, Cask Body Calculations [Ref. 26]).

The structural analyses of the cask body in RT-200 NTE 2004 (Cask Body Calculations [Ref. 26]) are performed for various individual loadings. As stated in Regulatory Guide 7.8 [Ref. 18], the stress results of the individual loadings are combined so that the combination of the loads considered correspond to the regulatory condition specified in this section. Table 2.6-1 and Table 2.6-2 provide matrices of the various individual loads and how they are combined to form the load combinations of the normal conditions of transport as specified in the Regulatory Guide 7.8. A discussion regarding the consideration of each load combination in the analyses is presented in the RT-200 NTE 2004 [Ref. 26].

Table 2.6-1 NCT Individual Loads for RT-200 Cask Body Analysis

LOAD NUMBER	INDIVIDUAL LOAD DESCRIPTION
1	Bolt Preload
2	Thermal Stress at hot environment
3	Thermal Stress at cold environment
5	Internal Pressure
7	0.3m End Drop, Cold thermal
8	0.3m End Drop, Hot thermal
9	0.3m Side Drop, Cold thermal
10	0.3m Side Drop, Hot thermal
11	0.3m Corner Drop, Cold thermal
12	0.3m Corner Drop, Hot thermal

Table 2.6-2 Summary of Load Combinations for NCT/ASME Service Level A

NCT LOAD COMBINATION			APPLICABLE INDIVIDUAL LOAD									
			IL-01	IL-02	IL-03	IL-05	IL-07	IL-08	IL-09	IL-10	IL-11	IL-12
Hot Environment			See Section 2.6.1									
Cold Environment			See Section 2.6.2									
Increased external pressure			See Section 2.6.4									
Reduced external pressure			See Section 2.6.3									
Transport shock and vibration			See Section 2.6.5									
Free Drop (0.3m)	End Drop	Cold	X		X		X					
		Hot	X	X		X		X				
	Side Drop	Cold	X		X				X			
		Hot	X	X		X				X		
	Corner Drop	Cold	X		X						X	
		Hot	X	X		X						X

The RT-200 is subjected to thermal stresses due to the differential thermal expansion between dissimilar materials. Two NCT thermal conditions (hot and cold) have been identified and the corresponding thermal stress results are used in the final load combinations as shown in Table 2.6-2. Additionally, during fabrication of the RT-200 cask, thermal stresses can be introduced in the inner and outer shells as a result of pouring molten lead between them. Residual stresses may be induced in the inner shell (containment boundary) and the outer shell due to shrinkage of the lead shielding subsequent to lead pouring operations; however, these stresses are relieved early in the life of the cask because of the low creep strength of lead. Therefore, the effects of

stresses resulting from the cask fabrication processes are considered negligible. RT-200 NTE 2004 [Ref. 26] details the evaluation that has led to this conclusion.
The analyses demonstrate that there is no decrease in the RT-200 Cask Package effectiveness as follows:

- no loss of dispersal of contents;
- no structural changes reducing the effectiveness of components required for shielding, for heat transfer, or for maintaining containment;
- no changes to the package affecting its ability to withstand HAC.

As described in Section 2.1.2.1, the design criteria specified in the ASME Code [Ref. 13] and in Regulatory Guide 7.6 [Ref. 14] require the stress results to be linearized and classified. Therefore, the stress results are evaluated on selected node locations, linearized, and classified according to the ASME Code classification rules presented in Section III.3. WB-3200. The reporting method for the RT-200 cask body stresses is summarized hereunder.

Figure 2.6-1 shows the selected locations on the cask body numbered 1 through 17 where the stress results are reported. For practical reasons, the reporting of stresses is limited to those locations shown in Figure 2.6-1. These were indeed selected for their relevance towards the stress distribution, with particular attention attached to areas of high stress. A path is defined for each selected location of the model. Running from the inside to the outside of the vessel, each path is used as a stress classification line (SCL) for the stress evaluation. Using the ANSYS stress linearization feature on each of the SCL allows for determination of the various stress intensities as defined in the ASME Code.

Figure 2.6-1 RT-200 Cask Body Stress Reporting Locations

[redacted]

Notes :

1) The stress result tables present the membrane stress intensity (averaged stress intensity across the selected stress classification line), the membrane plus bending stress intensity as well as the primary plus secondary stress intensity on the inner and outer surface of the components for all 17 locations.
2) The classification lines numbered 4, 5, 6 and 13 are located on gross structural discontinuities. There, the stress classification to use is discussed in ASME III.3.WB-3213.9.

A detailed discussion regarding the process of classification is presented in RT-200 NTE 2004 [Ref. 26].

Based on the ASME Table III.3.WB-3217, which presents some typical cases of stress intensity classification, Table 2.6-3 has been developed to categorize the various RT-200 cask body stresses for each SCL. Two categories of stress origins have been defined: the first one, the "mechanical loads" category corresponds to the combination of internal pressure, bolt preload and all impact loads including inertia; the second one, "the thermal loads" category corresponds to the thermal gradients and temperature differences between adjacent components produced by the thermal environment conditions.

Several points regarding the stress classification for the RT-200 cask body evaluation should be discussed.

The ASME Code differentiates the primary stresses from the secondary stresses. Primary stress corresponds to the stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium of external and internal forces and moments. Generally, pressure and mechanical loads, including inertia lead to primary stress (see ASME III.3 Figures WB-3222-1 and WB-3224.1-1). On the other hand, secondary stress is self-limiting, meaning that local yielding and minor distortions can satisfy the conditions that cause the stress to occur. As per RG 7.6, thermal stresses are secondary since they are strain-controlled rather than load-controlled, and these stresses decrease as yielding occurs.

A second differentiation is done between the membrane and the bending stress. The membrane stress, Pm, intensity is equal to the average value of the stress across the component's thickness. It corresponds to the component of normal stress that is uniformly distributed along the plane of reference. Bending stress, Pb, however, is the component of normal stress that varies along the SCL.

In addition to these definitions, the stress location is also relevant. In particular, the head-to-shell junctions are gross structural discontinuities as defined in ASME III.3.WB-3213.2. For these locations:

- the membrane stresses produced by mechanical loads are local primary membrane stresses as defined in ASME III.3.WB-3213.10;
- the bending stresses produced by mechanical loads are secondary stresses, Q, as discussed in ASME III.3.WB-3213.9.

Table 2.6-3 RT-200 Cask Body Stresses Classification

STRUCTURAL LOCATION	SCL	STRESS ORIGIN	STRESS TYPE	CLASSIFICATION
No discontinuity	1 2 3 7 8 9 10 11 12 14 15 16 17	Mechanical	Membrane	Pm
			Bending	Pb
		Thermal	Membrane	Q
			Bending	Q
Gross structural discontinuity	4 5 6 13	Mechanical	Membrane	Pl
			Bending	Q
		Thermal	Membrane	Q
			Bending	Q

2.6.1. Heat

The RT-200 cask body is analyzed for structural adequacy in accordance with the thermal evaluation of the RT-200 for the temperatures specified in 10 CFR 71.71(c)(1) [Ref. 10]. The thermal evaluation presented in Chapter 3 demonstrates that the cask component temperatures are maintained within their safe operating ranges for all normal conditions of transport. The following subsections describe the utilization of these results in the various structural evaluations.

2.6.1.1. Summary of Pressures and Temperatures

The pressures and temperatures occurring in the RT-200 as a result of the 10 CFR 71 [Ref. 10] normal thermal conditions are an important consideration for the structural evaluations presented in this chapter.

The temperatures affect the selection of temperature-dependent material properties as well as the internal pressures that occur as a result of the ambient temperatures and solar insolation specified in 10 CFR 71.71. The material properties utilized are based on the maximum calculated temperatures of each component or higher temperatures which are conservative. The maximum component temperatures in the RT-200 for normal conditions are presented in Chapter 3, Table 3.1-1. These temperatures are utilized to determine the stress allowables used in the structural evaluation.

The internal pressure induces stresses on the containment system. The maximum normal operating pressure evaluation for the RT-200 is presented in Chapter 3 Section 3.3.2. For conservatism, the Maximum Normal Operating Pressure is set to 200 kPa (abs.) and this value is used in the analyses.

2.6.1.2. Differential Thermal Expansion

As shown in Chapter 3, Table 3.1-1, the temperatures of the components of the cask differ by only a few degrees under the normal conditions of transport thermal ambient conditions. This difference is due in part to the relatively low decay heat of the contents. The RT-200 is evaluated for differential thermal expansion as described in Section 2.6.7 in combination with the other regulatory specified individual loads under the following conditions:

- Ambient temperature, 38°C
- Initial temperature, 38°C
- Heat transfer to ambient by natural convection, still air
- Heat transfer to ambient by radiation
- Steady-state solar insolation
- Internal heat load as a uniform heat flux, 67.82 W/m^2 (1200W total)

2.6.1.3. Stress Calculations

The stress intensities resulting from the hot thermal conditions previously described are determined using a 2D-axisymmetric model derived from the model used in the thermal analysis of Chapter 3. A detailed explanation of the model and methods used for the thermal stress evaluation is given in RT-200 NTE 2004 [Ref. 26]. The various thermal stress intensities are calculated on each selected stress classification line and combined with the stress results from the other normal conditions of transport loads (obtained with the finite element model described in Section 2.6.7.2.1) to form the normal load combinations. The combined resulting stresses are the primary membrane stress intensity, the primary membrane plus bending stress intensity and the primary plus secondary stresses, which are compared to the allowables to determine the safety margins.

2.6.1.4. Comparison with Allowable Stresses

The combined and classified stress results of the normal conditions of transport are presented in Appendix of RT-200 NTE 2004 [Ref. 26]. Since the margins of safety are all positive, the RT-200 cask design, therefore, satisfies the requirements of 10 CFR 71.71(c)(1) [Ref. 10] for the heat (normal transport) condition.

2.6.2. Cold

The RT-200 cask body is analyzed for structural adequacy in accordance with the thermal evaluation of the RT-200, for the temperatures specified in 10 CFR 71.71(c)(2) [Ref. 10], and presented in Chapter 3. The thermal evaluation demonstrates that the RT-200 component temperatures are maintained within their safe operating ranges for all normal conditions of transport. Using the methodology presented in Section 2.6.1.3 and 2.6.1.4, the RT-200 is evaluated for cold conditions.

The following thermal case is used to calculate the thermal stresses under cold conditions:

- Ambient temperature, -40°C
- Initial temperature, -40°C
- Heat transfer to ambient by natural convection, still air
- Heat transfer to ambient by radiation
- No solar insolation, in shade
- No decay heat of the radioactive material

Although RG 7.8 acknowledges a -29°C ambient temperature as the lower limit for the HAC and NCT analyses, the cold environment normal conditions (10 CFR 71.71 (c)) set a -40°C ambient temperature which is more conservative regarding the thermal expansion between dissimilar materials and is therefore used as the cold thermal condition for all NCT and HAC cases.

The combined stress results are presented in the Appendix of RT-200 NTE 2004 [Ref. 26]. Since the margins of safety are all positive, the RT-200, therefore, satisfies the requirements of 10 CFR 71.71(c)(2) [Ref. 10] for the cold (normal transport) condition.

2.6.3. Reduced External Pressure

A drop in atmospheric pressure to 24 kPa, as specified in 10 CFR 71.71(c) [Ref. 10] has a negligible effect on the RT-200 cask body. Indeed, this load condition is bounded by the free drop analyses performed at hot thermal environment in which a maximal internal pressure is applied in conjunction with a zero external pressure. Therefore, this load condition is not considered in the cask body structural evaluation.

2.6.4. Increased External Pressure

An increased external pressure of 140 kPa, as specified in 10 CFR 71.71(c) [Ref. 10] has a negligible effect on the RT-200 cask body because of the thick outer shell and end closures of the cask. Section 2.6.7 addresses many different loadings which exceed these pressure requirements. Therefore, this load condition is not considered in the cask body structural evaluation.

2.6.5. Vibration

The cask is evaluated for the shock and vibration environment normally incident to transport, as specified in regulatory position 2.5 of RG 7.8 [Ref. 18]. The fatigue analysis for the cask is provided in Appendix 2.12.3.

The transport shock and vibration loading inputs are derived from NUREG/CR-0128 [Ref. 28], which describes the shock and vibration environments measured during truck shipment of a 25,000 kg container. Since the mass of the container used in those measurements is inferior to the RT-200 cask's mass, it is conservative to directly use the transport inertia values given by NUREG/CR-0128.

According to NUREG/CR-0128, the maximum expected severities of shocks (superimposed on and mixed with vibration) are the following:

- A vertical acceleration of 2.2 g
- A longitudinal acceleration of 1.6 g
- A horizontal transverse acceleration of 2.9 g

The resultant loading is 3.976 g (given by $\sqrt{2.2^2 + 1.6^2 + 2.9^2}$), which is considerably inferior to the smallest of the g-loads applied in the NCT free-drop loading combinations.

According to NUREG/CR-0128, the highest levels of truck input vibration are the following:

- A longitudinal acceleration of 0.27 g
- A transverse acceleration of 0.19 g
- A vertical acceleration of 0.52 g

The resultant loading is 0.616 g (given by $\sqrt{0.27^2 + 0.19^2 + 0.52^2}$), which is considerably inferior to the smallest of the g-loads applied in the NCT free-drop loading combinations.

Both shocks and vibration loads are negligible compared to the g-loads applied in the NCT free-drop loading combinations. Therefore, these load conditions are not considered in the load combinations under NCT.

However, vibration loads normally incident to transport contribute to mechanical fatigue. The latter is evaluated in the fatigue analyses presented in Appendix 2.12.3. The analyses show that the RT-200 cask design meets all fatigue requirements during transport.

Additionally, since closure bolts are reused, they are also analyzed for fatigue as described in Appendix 2.12.3.7.

2.6.6. Water Spray

Water causes negligible corrosion of the stainless shells of the RT-200. The cask contents are protected in the sealed cavity. A water spray as specified in 10 CFR 71.71(c)(6) [Ref. 10] has no adverse impact on the package. The cask surface temperature specified during the water spray is between 38°C and -29°C. Consequently, the induced thermal stress in the cask components is less than the thermal stresses that occur during the extreme temperature conditions for normal transport. Therefore, the requirements of 10 CFR 71.71(c)(6) [Ref. 10] are satisfied.

2.6.7. Free Drop

The RT-200 is shown to meet the free drop requirements of 10 CFR 71.71 [Ref. 10] through a combination of classic calculations (RT-200 NTE 2101, Drop Calculations [Ref. 25]) and finite elements analyses (RT-200 NTE 2004, Cask Body Calculations [Ref. 26]). The evaluations include the qualification of the RT-200 closure bolt design for the combined effects of free drop impact force, internal pressures, thermal stress, and bolt preload following the methodology of NUREG/CR-6007 [Ref. 15]. This qualification has been performed in RT-200 NTE 2005, Closure Bolt Evaluation [Ref. 29].

The combined effects of impact loads, inertial loads, internal pressures, and thermal stress are considered for packaging components. The input data is derived from the results of RT-200 NTE 2101, Drops Calculations [Ref. 25] and corresponds to the impact limiter's reaction forces applied to the cask body. As explained in RT-200 NTE 2101 [Ref. 25], the normal conditions of transport include the End-Drop, the Side-Drop, and the Corner-Drop configurations. Each of the free-drop loadings is analyzed in combination with two sets of environmental conditions, as shown in the load combination summary of RG 7.8 [Ref. 18].

2.6.7.1. Methodology

The RT-200 is designed in accordance with the ASME Code [Ref. 13] and Regulatory Guide 7.6 [Ref. 14]. The design criteria for NCT and HAC are presented in Table 2.1-1. Load combinations for the structural analysis of shipping casks for radioactive materials are defined by Regulatory Guide 7.8 [Ref. 18]. The load combinations for all normal and accident conditions and corresponding ASME service levels are shown in Table 2.6-2 and Table 2.7-2. Material properties used in this evaluation are presented in Section 2.2. Stress intensities caused by thermal loads and mechanical loads are combined before comparing to stress allowables, which are listed in Table 2.2-1.

Calculations are performed using finite element modeling techniques, employing ANSYS finite element code [Ref. 30]. NTE 2004, Cask Body Calculations [Ref. 26] provides further details of all methods, models, results, and discussions that are summarized hereunder.

The outline shape of the cask body is a sealed cylinder. The major components are the inner and outer shell, the lead shielding in between, the lid, the bolts, and washers as well as the bottom and top forging. Two different numerical models of the cask were used to perform the various analyses for the normal conditions of transport load combinations. These are presented hereunder and detailed in Section 2.6.7.2:

- A 2D axisymmetric model including all major components except bolts and washers, for thermal stress evaluation. It is assumed that the stress distribution resulting from the various thermal conditions of RG 7.8 [Ref. 18] is axisymmetric and can therefore be reported on every 2D radial cross-section of the cask body. This model has been derived from the model utilized in the thermal analyses of Chapter 3.
- A 3D "complete" axisymmetric model including all major components, utilized for the transient structural evaluation of the stress resulting from all loads including bolt preload, free drop loads and internal pressure.

Except for the side puncture drop and the fabrication stresses due to lead pouring and cool down, which are analytically evaluated, all individual loads are applied to the models via boundary conditions and evaluated using the ANSYS computer program.

The following boundary conditions are applied to the models, simulating the loading conditions the cask body will experience during normal and accident transport conditions:

- Pressure loads are applied to the cask body inner shells to simulate internal pressurization;
- Content load actions are applied as a distributed mass over the corresponding inner cavity surface;
- Bolt preloads are applied to represent the bolt pretension at the time the cask is prepared for shipment. The value of the preload is derived from RT-200 NTE 2005, Closure Bolt Evaluation [Ref. 29];
- Loads exerted by the impact limiters on the cask body are simulated by external surface loads which magnitudes, directions and application areas are defined according to the results of RT-200 NTE 2101, Drops Calculations [Ref. 25];
- Loads exerted by the pin in the case of the lid puncture are simulated by an external pressure;
- [redacted]

[redacted]

The stress results are evaluated on selected node locations, linearized, and classified according to the ASME Code classification rules presented in Section III.3. WB-3200. The reporting method for the RT-200 cask body stresses is presented in Section 2.6.

2.6.7.2. Models Description

2.6.7.2.1. <u>3D "Complete" Model Description</u>

Each load combination is analyzed using a three-dimensional finite elements model with the computational modeling software ANSYS [Ref. 30]. The FE model is axisymmetric and represents half of the RT-200 cask body.

The precision needed for the FE model requires simplifying certain geometric singularities. Thus, the following geometric simplifications are realized:

- Chamfers are only considered when they bring a major change to the geometry;
- Joint grooves are not represented;
- Fillets that impose excessive constraints on meshing techniques are not represented;

- Holes in the material allowing the passage of elements are not modeled;
- Only dimensional structural parts are shown.

Figure 2.6-2 shows a global view of the complete cask body solid model. The FE Model is generated by defeaturing the SolidWorks® [Ref. 31] solid model used to develop the manufacturing drawings and exporting the model to a .STEP file format. The .STEP file is imported directly into ANSYS where the FE Model is developed (Figure 2.6-3).

The components constitutive of the 3D “complete” model are:

- The inner shell and outer shell (stainless steel)
- The bottom and top forging as well as the closure lid (stainless steel)
- The bolts and washers (stainless steel)
- The shielding layer between the inner and outer shells (lead)

Figure 2.6-2 3D "Complete" Model (unmeshed)

[redacted]

Figure 2.6-3 3D "Complete" Model (meshed)

[redacted]

The mesh has been developed according to the following process:

- The solid portion of the model is constructed using ANSYS solid (SOLID186) elements;
- The interaction between adjacent components, which is summarized in Table 2.6-4, is simulated using surface-to-surface contact elements (CONTACT174/TARGET170).

Table 2.6-4 3D "Complete" Model Contact Regions

CONTACT COMPONENT	TARGET COMPONENT	CONTACT TYPE
Inner Shell	Bottom Forging	[redacted]
Outer Shell	Bottom Forging	
Inner Shell	Top Forging	
Outer Shell	Top Forging	
Outer Shell Components		
Lead	Bottom Forging	
Lead	Outer Shell	
Lead	Inner Shell	
Lead	Top Forging	
Bolts	Washers	
Washers	Lid	
Lid	Top Forging	
Bolts	Top Forging	

Notes:

[redacted]

[redacted]

During the development of the finite elements model each part was considered on an individual basis. The forgings and the lid were meshed using a hex dominant method. The shells were meshed with a sweep method and the element size was varied until there was a sufficient number of elements across the shell thickness.

An optimal element size was determined to reach a good compromise between run time and results precision. To do so, a portion of each shell was modelled. The ends of the tested portion were fixed, loads were applied to simulate the same stress distribution as the one that leads to the most critical stress and a solution was obtained. Several cases were run to vary the total mesh density to determine how the stress results varied versus performance of the model. After numerous runs a balance was found between consistent results and model performance with variations of stress results of approximately 1% when comparing high mesh densities to adequate mesh densities. Therefore, it was concluded that the cask model was a quality model. This mesh sensitivity analysis is presented in the Appendix of RT-200 NTE 2004, Cask Body Calculations [Ref. 26].

2.6.7.2.2. 3D "Complete" Model Boundary Conditions

Boundary conditions are applied to the model to simulate the loading conditions the RT-200 experiences during NCT and HAC. The five categories of boundary conditions applied to the model are closure lid bolt preload, internal pressure loads, external surface loads, inertial body loads and displacements. Each boundary condition is described in the following subsections and detailed representations are shown in RT-200 NTE 2004, Cask Body Calculations [Ref. 26].

2.6.7.2.2.1. Closure Lid Bolt Preload

The required total bolt preload on each bolt of the closure lid is [redacted], as calculated in RT-200 NTE 2005, Closure Bolt Evaluation [Ref. 29]. To apply the preload, ANSYS pre-tension elements are used. These elements use a single translation degree of freedom to define pretension direction. This allows simulating the closure lid's fixation on the top forging during free drops.

2.6.7.2.2.2. Internal Pressure

A pressure of 200 kPa (abs.) is used to envelope the maximum normal operating pressure (see RT-200 NTE 3003, Pressures Calculation [Ref. 32]. The internal pressure load is uniformly applied on the interior surface of the cask, bounded by the inner O-ring.

2.6.7.2.2.3. Impact Limiter Reaction Force

During impact the shock absorber is crushed between the cask body and the ground surface. Thus, for each drop case, the impact limiter generates a force distributed over a surface of the cask body which depends on the crush depth and cask orientation. For each drop configuration, the impact limiter reaction force is applied as a transient force for which the time curve has been extracted from RT-200 NTE 2101, Drops Calculations [Ref. 25]. Further details about the application area of the impact limiter's reaction for each drop case are given in the following.

- End-Drop: The impact limiter's reaction force is distributed over the lower circular surface of the bottom forging.
- Side-Drop: The impact limiter's reaction force is distributed over two areas corresponding to the two impact limiters. These contact areas are defined by the projection of the crush section onto the cask body external surface and therefore depend on the crush depth achieved by each impact limiter in [Ref. 25].
- Corner-Drop: The impact limiter's reaction force is distributed over the area corresponding to the vertical projection of the crush section over the cask body external surface. The crush section is derived from the crush depth determined in [Ref. 25].

2.6.7.2.2.4. Content Pressure Loading

The action of the content on the inner cavity depends on the drop configuration. Detailed representations of the content load distribution for each drop case are presented in [Ref. 26].

- <u>End Drop:</u> For the end-drop analyses, the content weight is assumed to be uniformly distributed on the cask end and over an area determined by the inside diameter of the cask. Therefore, one half of the content's weight is considered and applied to the bottom plate.
- <u>Side-Drop:</u> For the side-drop analyses, the contact area between the content and the cask cavity is approximately 180° (90° on each side of the drop centerline). The load produced by one half of the contents weight is represented as a mass distributed on the interior surface of the cask.
- <u>Corner-Drop:</u> For the corner-drop analyses, the load produced by one half of the content's weight is represented as a distributed mass applied on the lid and on the lower half of the front forging along the cask's axis.

2.6.7.2.2.5. Displacement Boundary Conditions

Displacement boundaries are applied for two reasons:

- To enforce symmetry at the cut boundary of the 3D model: all nodes on the symmetry plane are fixed in the perpendicular-to-plane direction;
- In the case of steps without time integration (static steps):
    - to fixate all the model's degrees of freedom and thus ensure there is no rigid body motion;
    - to assign a given displacement to the global assembly and thus generate the velocity corresponding to the initial velocity of the impact.

The various vertices on which displacement boundary conditions are applied are shown in Figure 2.6-4.

Figure 2.6-4 Displacement Boundary Conditions

[redacted]

2.6.7.2.3. <u>2D Model Description</u>

The cask temperature distribution calculated for the cold and hot thermal conditions described in Sections 2.6.1 and 2.6.2 is used as an input to the ANSYS thermal stress evaluation. The corresponding analyses are performed on a 2D axisymmetric model derived from the model used in the thermal evaluation of the RT-200 cask. Using a 2D model is acceptable because the temperature distribution in the cask body is assumed to be axisymmetric. This assumption is correct since there are no considerable material discontinuities that provide axial dissymmetry.

Figure 2.6-5 shows the 2D model (unmeshed and meshed) used for the thermal stress calculation. This model is composed of the inner and outer shell, the lead shielding, and the top and bottom forging.

The bolts and washers have not been represented. The closure bolt evaluation [Ref. 29] indeed already considers thermal aspects involved in the bolted connection of the lid to the top forging.

The mesh has been developed according to the following process:

- The model has been constructed using ANSYS plane (PLANE183) elements;
- The interaction between adjacent components, which is summarized in Table 2.6-5 is simulated using ANSYS 2-D contact elements (CONTA172).

During the development of the finite elements model, the element size was varied until there was a sufficient number of elements across the shells thickness.

Figure 2.6-5 2D Axisymmetric Model (unmeshed and meshed)

[redacted]

Table 2.6-5 2D Axisymmetric Model Contact Regions

CONTACT COMPONENT	TARGET COMPONENT	CONTACT TYPE
Lid	Shells and Forgings (1)	[redacted]
Lead	Shells and Forgings (1)	

Notes:

[redacted]

2.6.7.2.4. <u>2D Model Boundary Conditions</u>

2.6.7.2.4.1. Temperature Distribution

As described in Table 2.6-2 and in Table 2.7-2, the stress distribution resulting from the hot and cold thermal conditions is assessed and combined with the stress resulting from other loads to assess the acceptability of the RT-200 cask body towards regulatory requirements.

Chapter 3 uses a 2D axisymmetric model to evaluate the cask's thermal performances. These analyses result in a temperature distribution for the hot and fire accident conditions, which respectively correspond to the "Heat" and "Thermal" cases of 10 CFR 71 [Ref. 10]. Trivially, the temperature distribution obtained for the "Cold" thermal condition is a uniform distribution with -40°C at any point of the cask body.

The temperature distributions are applied to the mechanical model using the following process:

- The temperature distributions are obtained from the results file by writing the results to an ASCII file, in which a temperature is assigned to each node location of the thermal model;
- The temperature distribution is imported as a load to the mechanical model. The import is performed using interpolation to assign a temperature at any location on the model. This allows to determine the stress arising from the thermal expansion of the cask from its initial 21°C state (which corresponds to the zero-strain state) to its final state which corresponds to the selected temperature distribution obtained under the thermal environment condition.

[Ref. 26] shows the temperature distributions used as inputs for the thermal stress evaluations.

2.6.7.2.4.2. Displacement Boundary Conditions

To fixate all degrees of freedom and ensure the model is not subjected to rigid body motion, the displacement of one node is fixated in the longitudinal direction. The node selected for fixation is the node located on the periphery of the bottom plate.

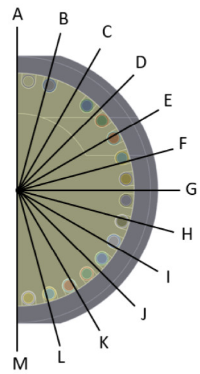
2.6.7.3. Reporting Method for the NCT Cask Body Stresses

Figure 2.6-6 shows the selected locations on both the 3D "complete" model and the 2D model, numbered 1 through 17. Additionally, for the 3D model, stress results have been observed on 13 distinct section planes marked as A through M. These planes are shown in Figure 2.6-7. For each drop configuration, the stress intensities are evaluated on all locations of each cross-sectional plane.

Figure 2.6-6 Stress Reporting Locations (3D and 2D Models)

[redacted]

Figure 2.6-7 Planes used for Stress Reporting in the 3D Model



2.6.7.4. NCT Free Drops Results

The stress results obtained under mechanical and thermal loads in normal transport conditions are combined as per Table 2.6-2. For each of the NCT load combinations studied (end-drop, side-drop, and corner-drop), safety margins are calculated and the most critical stress states in terms of safety margin are presented together with their locations.

The following subsections present, for each of the normal conditions of transport load combinations:

- the graphical stress distributions resulting from the mechanical loads that are participative of the load combination (distributions are presented for each individual structural component);
- the corresponding safety margins for each of the classified stress intensities (Primary Membrane, Primary Membrane and Bending, Primary and Secondary) determined for each SCL.

Notes:

- The safety margin is calculated using the following formula:

$$Safety\ Margin = \frac{Allowable\ Stress\ Intensity}{Calculated\ Stress\ Intensity} - 1$$

- For a given SCL, the design criteria on a classified stress intensity is considered to be fulfilled if the Safety Margin is positive.

2.6.7.4.1. NCT End-Drop

In accordance with the requirements of 10CFR71.71 [Ref. 10], the RT-200 is structurally evaluated for the NCT End-Drop. The results of the 0.3-meter end-drop are combined with those resulting from thermal environments as per Table 2.6-2.

Safety margins corresponding to this load combination are documented in Table 2.12-4 in the Appendix. The margins of safety are positive when compared to the stress intensity for each category. [redacted]

The minimum margins of safety are:

- +3.0 for primary membrane stress intensity on SCL D08
- +4.6 for primary membrane plus bending stress intensity on SCL D08
- +50.2 for primary plus secondary stress intensity on SCL 07

Figure 2.6-8 and Figure 2.6-9 show the assembly stress distribution relative to the 0.3-meter end-drop, respectively cold and hot environment conditions.

Figure 2.6-8 RT-200 Stress Intensity Results (0.3-meter end-drop at -40°C)

[redacted]

Figure 2.6-9 RT-200 Stress Intensity Results (0.3-meter end-drop at 80°C)

[redacted]

Figure 2.6-10 through Figure 2.6-14 show the stress distributions in each of the structurally evaluated component for the cold environment.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.6.7.4.2. NCT Side-Drop

In accordance with the requirements of 10CFR71.71 [Ref. 10], the RT-200 is structurally evaluated for the NCT Side-Drop. The results of the 0.3-meter side-drop are combined with those resulting from thermal environments as per Table 2.6-2.

Safety margins corresponding to this load combination are documented in Table 2.12-5 in the Appendix. The margins of safety are positive for each category of stress intensity. [redacted]

The minimum margins of safety are:

- +0.6 for primary membrane stress intensity on SCL M11
- +0.7 for primary membrane plus bending stress intensity on SCL M10
- +2.8 for primary plus secondary stress intensity on SCL M13

Figure 2.6-15 and Figure 2.6-16 show the assembly stress distribution relative to the 0.3-meter side-drop, respectively cold and hot environment conditions.

[redacted]

[redacted]

Figure 2.6-17 through Figure 2.6-25 show the stress distributions in each of the structurally evaluated component for the cold environment.

[redacted]

[redacted]

[redacted]

[redacted]

2.6.7.4.3. NCT Corner-Drop

In accordance with the requirements of 10CFR71.71 [Ref. 10], the RT-200 is structurally evaluated for the NCT Corner-Drop. The results of the 0.3-meter corner-drop are combined with those resulting from thermal environments as per Table 2.6-2.

Safety margins corresponding to this load combination are documented in Table 2.12-6 in the Appendix. The margins of safety are positive for each category of stress intensity. [redacted]

The minimum margins of safety are:

- +7.7 for primary membrane stress intensity on SCL K07
- +4.9 for primary membrane plus bending stress intensity on SCL K07
- +11.0 for primary plus secondary stress intensity on SCL C06

Figure 2.6-26 and Figure 2.6-27 show the assembly stress distribution relative to the 0.3-meter corner-drop, respectively cold and hot environment conditions.

[redacted]

[redacted]

Figure 2.6-24 through Figure 2.6-28 show the stress distributions in each of the structurally evaluated component for the cold environment.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.6.8. Corner Drop

This section specifically addresses the « Corner Drop » Test of 10 CFR 71.71(c)(8) [Ref. 10].

The RT-200 is composed of materials other than fiberboard or wood. Also, the weight of the RT-200 exceeds 100 kg. According to 10 CFR 71.71(c)(8) [Ref. 10], the corner drop test is not applicable to the RT-200.

2.6.9. Compression

According to 10 CFR 71.71(c)(9) [Ref. 10], the compression test is not applicable to the RT-200 because the package weight is greater than 5,000 kg.

2.6.10. Penetration

According to 10 CFR 71.71(c)(10) [Ref. 10], a penetration test involving a 13-lb (6-kg) penetration cylinder dropped from a height of 1 m is required for evaluation of packages during normal conditions of transport. However, Regulatory Guide 7.8 [Ref. 18] states that “the penetration test of 10 CFR 71.71 [Ref. 10] is not considered by the NRC staff to have structural significance for large shipping casks (except for unprotected valves and rupture disks) and is not considered as a general requirement.” A penetration test is not performed since the RT-200 has no unprotected valves or rupture disks that could be affected by normal conditions of transport.

2.7. HYPOTHETICAL ACCIDENT CONDITIONS

This section describes the RT-200's evaluation for the hypothetical accident conditions of transport specified in 10 CFR 71.73 [Ref. 10]. The requirements of 10 CFR 71.73 state that the RT-200 shall be structurally adequate for the hypothetical accident conditions, which are addressed in the following subsections:

- free drop
- crush
- puncture
- thermal
- immersion – fissile material
- immersion – all packages

Detailed structural analyses are provided in [Ref. 26]. The analyses demonstrate the capability of the RT-200 cask's design to meet the regulatory requirements in the context of the hypothetical accident conditions of transport load combinations specified in 10 CFR 71 and Regulatory Guide 7.8 [Ref. 18].

The same method involving two steps and used for the free drop analyses in the normal conditions of transport is used in the free drop analyses of the accident transport conditions. The first step consists in the calculation of the crushing forces and g-loads the cask is subjected to (RT-200 NTE 2101, Drops Calculations [Ref. 25]). As an example, Appendix 2.12.6, Section 2.12.6.1 provides details about the general method as well as the formulas used to specifically evaluate the 9-meter end-drop. The same method has been followed for the evaluations of all the other drop cases and the latter are presented in detail in [Ref. 25]. In the second step, the calculated forces are used as inputs to numerical simulations to determine the stress intensities in the cask body (RT-200 NTE 2004, Cask Body Calculations [Ref. 26]).

The structural analyses of the cask body in RT-200 NTE 2004 [Ref. 26] are performed for various individual loadings. As stated in Regulatory Guide 7.8 [Ref. 18], the stress results of the individual loadings are combined so that the combination of the loads considered correspond to the regulatory conditions specified in this section. Table 2.7-1 and Table 2.7-2 provide matrices of the various individual loads and how they are combined to form the load combinations of the hypothetical accident conditions of transport as specified in the Regulatory Guide 7.8. A discussion regarding the consideration of each load combination in the analyses is presented in the RT-200 NTE 2004 [Ref. 26].

Table 2.7-1 HAC Individual Loads for RT-200 Cask Body Analysis

LOAD NUMBER	INDIVIDUAL LOAD DESCRIPTION
1	Bolt Preload
2	Thermal Stress at hot environment
3	Thermal Stress at cold environment
4	Thermal Stress at fire environment
5	Internal Pressure
6	HAC Internal Pressure
13	9m End Drop, Cold thermal
14	9m End Drop, Hot thermal
15	9m Side Drop, Cold thermal
16	9m Side Drop, Hot thermal
17	9m Corner Drop, Cold thermal
18	9m Corner Drop, Hot thermal
19	Slap Down Drop, Cold thermal
20	Slap Down Drop, Hot thermal
21	Puncture, Cold Thermal
22	Puncture, Hot Thermal

Table 2.7-2 Summary of Load Combinations for Hypothetic Accident Conditions of Transport

HAC LOAD COMBINATION			APPLICABLE INDIVIDUAL LOAD															
			IL-01	IL-02	IL-03	IL-04	IL-05	IL-06	IL-13	IL-14	IL-15	IL-16	IL-17	IL-18	IL-19	IL-20	IL-21	IL-22
Free Drop (9 m)	End Drop	Cold	X		X				X									
		Hot	X	X			X			X								
	Side Drop	Cold	X		X						X							
		Hot	X	X			X					X						
	Corner Drop	Cold	X		X								X					
		Hot	X	X			X							X				
	Slap Down	Cold	X		X										X			
		Hot	X	X			X									X		
Puncture		Cold	X		X												X	
		Hot	X	X			X											X
Thermal		Fire	X			X		X										

In addition to the two thermal conditions (hot and cold) evaluated for stress due to differential thermal expansion between dissimilar materials, the structural evaluation of the RT-200 under

HAC involves a third thermal condition, which is described hereunder as the fire condition and which corresponds to the thermal environment of 10 CFR 71.73(c)(4) [Ref. 10].

The reporting locations for the stress intensities are the same as for the normal conditions of transport.

2.7.1. Free Drop

The RT-200 is shown to meet the free drop requirements of 10 CFR 71.73 [Ref. 10] through a combination of classic calculations (RT-200 NTE 2101, Drop Calculations [Ref. 25]) and finite elements analyses (RT-200 NTE 2004, Cask Body Calculations [Ref. 26]). The evaluations include the qualification of the RT-200 closure bolt design and its ability to maintain positive closure for the combined effects of free drop impact force, internal pressures, thermal stresses, and bolt preload following the methodology of NUREG/CR-6007 [Ref. 15]. This qualification has been performed in RT-200 NTE 2005, Closure Bolt Evaluation [Ref. 29].

The combined effects of inertial loads, internal pressures, and thermal stress are considered for packaging components. The input data is derived from the results of RT-200 NTE 2101, Drops Calculations [Ref. 25] and corresponds to the impact limiter's reaction forces applied to the cask body. As explained in RT-200 NTE 2101 [Ref. 25], the hypothetical accident conditions of transport include the End-Drop, the Side-Drop, the Corner-Drop, and the Slap-Down Drop configurations. Each of the free-drop loadings is analyzed in combination with two sets of environmental conditions, as shown in the load combination summary of RG 7.8 [Ref. 18].

The methods, models and boundary conditions used for the structural evaluation of the RT-200 cask body under the hypothetical accident conditions of transport free drops are the same as those presented in Section 2.6.7.1. The slap-down drop, which is not evaluated in the normal conditions of transport, is analyzed with similar boundary conditions as the side-drop:

- The displacement boundary conditions are the same;
- The content pressure loading is applied on the same contact area;
- The impact limiter reaction force to consider in the calculations is the force applied by the front impact limiter on the cask body during the 2nd impact. The load is therefore distributed over one area corresponding to the vertical projection of the front impact limiter's crush section on the cask body.

Detailed representations of the various boundary conditions are shown in RT-200 NTE 2004, Cask Body Calculations [Ref. 26].

The stress results obtained under mechanical and thermal loads in hypothetical accident conditions of transport are combined as per Table 2.7-2. For each of the HAC free drop load combinations studied (end-drop, side-drop, corner-drop and slap-down), safety margins are calculated and the most critical stress states in terms of safety margin are presented together with their location.

The following subsections present, for each of the normal conditions of transport load combinations:

- the graphical stress distributions resulting from the mechanical loads that are participative of the load combination (distributions are presented for each individual structural component);
- the corresponding safety margins for each of the classified stress intensities (Primary Membrane, Primary Membrane and Bending, Primary and Secondary) determined for each SCL.

Notes:

- The safety margin is calculated using the following formula:

$$Safety\ Margin = \frac{Allowable\ Stress\ Intensity}{Calculated\ Stress\ Intensity} - 1$$

- For a given SCL, the design criteria on a classified stress intensity is considered to be fulfilled if the Safety Margin is positive.

2.7.1.1. End-Drop

In accordance with the requirements of 10 CFR 71.73 [Ref. 10], the RT-200 is structurally evaluated for the HAC End-Drop. The results of the 9-meter end-drop are combined with those resulting from thermal environments as per Table 2.7-2.

Safety margins corresponding to this load combination are documented in Table 2.12-7 in the Appendix. The margins of safety are positive when compared to the stress intensity for each category. [redacted]

The minimum margins of safety are:

- +2.8 for primary membrane stress intensity on SCL E08
- +3.7 for primary membrane plus bending stress intensity on SCL E08
- +122.4 for primary plus secondary stress intensity on SCL H06

Figure 2.7-3 and Figure 2.7-4 show the assembly stress distribution relative to the 9-meter end-drop, respectively cold and hot environment conditions.

Figure 2.7-3 through Figure 2.7-7 show the stress distributions in each of the structurally evaluated component for the cold environment.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.7.1.2. Side-Drop

In accordance with the requirements of 10 CFR 71.73 [Ref. 10], the RT-200 is structurally evaluated for the HAC Side-Drop. The results of the 9-meter side-drop are combined with those resulting from thermal environments as per Table 2.7-2.

Safety margins corresponding to this load combination are documented in Table 2.12-8 in the Appendix. The margins of safety are positive when compared to the stress intensity for each category. [redacted]

The minimum margins of safety are:

- +0.9 for primary membrane stress intensity on SCL M11
- +0.7 for primary membrane plus bending stress intensity on SCL M10
- +8.8 for primary plus secondary stress intensity on SCL B13

Figure 2.7-8 and Figure 2.7-9 show the assembly stress distribution relative to the 9-meter side-drop, respectively cold and hot environment conditions.

Figure 2.7-10 through Figure 2.7-14 show the stress distributions in each of the structurally evaluated component for the cold environment.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.7.1.3. Corner Drop

In accordance with the requirements of 10 CFR 71.73 [Ref. 10], the RT-200 is structurally evaluated for the HAC Corner-Drop. The results of the 9-meter corner-drop are combined with those resulting from thermal environments as per Table 2.7-2.

Safety margins corresponding to this load combination are documented in Table 2.12-9 in the Appendix. The margins of safety are positive when compared to the stress intensity for each category. [redacted]

The minimum margins of safety are:

- +1.6 for primary membrane stress intensity on SCL M04
- +1.3 for primary membrane plus bending stress intensity on SCL K07
- +11.1 for primary plus secondary stress intensity on SCL B06

Figure 2.7-15 and Figure 2.7-16 show the assembly stress distribution relative to the 9-meter corner-drop, respectively cold and hot environment conditions.

Figure 2.7-17 through Figure 2.7-21 show the stress distributions in each of the structurally evaluated component for the cold environment.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.7.1.4. Oblique Drops

In accordance with the requirements of 10 CFR 71.73 [Ref. 10], the RT-200 is structurally evaluated for the HAC Slap Down Drop. The results of the 9-meter slap-down drop are combined with those resulting from thermal environments as per Table 2.7-2.

Safety margins corresponding to this load combination are documented in Table 2.12-10 in the Appendix. The margins of safety are positive when compared to the stress intensity for each category. [redacted]

The minimum margins of safety are:

- +1.7 for primary membrane stress intensity on SCL A04
- +1.5 for primary membrane plus bending stress intensity on SCL J07
- +11.0 for primary plus secondary stress intensity on SCL E06

Figure 2.7-22 and Figure 2.7-23 show the assembly stress distribution relative to the 9-meter slap-down drop, respectively cold and hot environment conditions.

Figure 2.7-24 through Figure 2.7-28 show the stress distributions in each of the structurally evaluated component for the cold environment.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.7.1.5. *Summary of Results*

Structural analyses are performed for the RT-200 for hypothetical accident condition free drop scenarios. To evaluate the RT-200, 3D ANSYS [Ref. 30] is used to analyze the governing drop cases. All structural members have a positive margin of safety under worst case loading conditions. Additionally, the lead slump has been evaluated for each of the free drop configurations. [redacted] The latter value is considerably inferior to the value conservatively considered in the shielding analyses of Chapter 5.

It is concluded that the RT-200 is structurally adequate for the HAC free drop conditions. Therefore, the requirements of 10 CFR 71.73(c)(1) [Ref. 10] have been satisfied.

[redacted]

2.7.2. Crush

In accordance with the requirements of 10 CFR 71.73(c)(2) [Ref. 10], the crush test is required only when the specimen has a mass not greater than 500 kg, and overall density not greater than 1,000 kg/m³ based on external dimension. The crush condition is not applicable since the RT-200 weighs more than 500 kg and overall density is greater than 1,000 kg/m³.

2.7.3. Puncture

In accordance with the requirements of 10 CFR 71.73(c)(3) [Ref. 10] related to puncture (hypothetical accident condition), the RT-200 cask is analyzed for structural adequacy (RT-200 NTE 2004, Cask Body Calculations [Ref. 26]). The cask is assumed to be dropped from a 1 meter height onto a 15 cm diameter mild steel bar oriented vertically on an unyielding surface. The structural evaluation of the RT-200 towards the regulatory puncture drop is performed by classical analytical calculation and finite element analysis methods.

2.7.3.1. Lid Puncture

Finite element analysis methods are used to perform the stress evaluation of the RT-200 for the lid puncture condition. The lid puncture is analyzed using a three-dimensional finite elements model using the computational modeling software ANSYS [Ref. 30]. To simplify the pin puncture analysis, only the upper end of the cask is considered for this evaluation.

2.7.3.1.1. <u>Methodology</u>

Similar methods of stress reporting and classification as in section 2.6 have been used for the evaluation of the RT-200 cask body's capability to meet the structural requirements of the ASME Code and RG 7.6 [Ref. 14]. The same hot and cold thermal conditions as in Sections 2.6.1 and

2.6.2 have been used to derive the stresses due to the thermal expansion between dissimilar materials and the lid puncture has been evaluated for two distinct environment temperatures corresponding to the hot and cold conditions, as described in RG 7.8 [Ref. 18].

2.7.3.1.1.1. 3D "Puncture" Model Description

To simplify the pin puncture, only the upper end of the cask is considered for this evaluation. Therefore, the 3D-axisymmetric "puncture" model used for the lid puncture numerical evaluation is slightly different from the "complete" model used for the previous numerical analyses.

Thus, the components constitutive of the 3D "puncture" model are:

- The top forging and closure lid (stainless steel)
- The bolts and washers (stainless steel)

Apart from its component parts, the "puncture" model is the same as the "complete" model described in Section 2.6.7.2.1 and used for other loads. Figure 2.7-30 shows the unmeshed and meshed model used for the puncture evaluation.

[redacted]

2.7.3.1.1.2. 3D "Puncture" Model Boundary Conditions

Boundary conditions are applied to the "puncture" model to simulate the loading conditions the RT-200 experiences during lid puncture.

The puncture load is applied to a 150 mm diameter region which corresponds to a 150 mm diameter pin. The load is simulated with an evenly distributed pressure load equal to the dynamic flow stress of the pin; the dynamic flow stress is taken to be 324 MPa (approximately 47,000 psi). This value of flow stress is extracted from the true stress-strain curve for 20°C annealed mild steel in chapter 5 of "Mark's Standard Handbook for Mechanical Engineers" [Ref. 34] and corresponds to the stress required to bring approximately 5% plastic deformation in the pin.

The bolt preload is included as an initial condition. In addition, the maximum normal operating pressure of 200 kPa (abs.) is applied to the inner cavity in the case of the hot environment.

The following displacement boundary conditions are applied:

- A symmetry boundary condition is applied at the cut boundary of the 3D model: all nodes on the symmetry plane are fixed in the perpendicular-to-plane direction;
- Additional boundary conditions are applied on selected nodes to fixate all degrees of freedom isostatically.

Eventually, since the pin puncture is evaluated in a static analysis, translational acceleration is implemented to compensate for the forces applied on the model, the numerical problem is solved by balancing the total puncture force by the total inertial loading. For the static finite element structural analysis to converge, suitable boundary conditions are selected to ensure that there is no rigid body motion. Thus, the model is restrained in such a way that no reaction forces are developed at the restrained nodes. The model is correctly balanced when negligible reaction forces are measured at these nodes.

2.7.3.1.2. Lid Puncture Results

In accordance with the requirements of 10 CFR 71.73 [Ref. 10], the RT-200 is structurally evaluated for the HAC Lid Puncture. The stress intensities resulting from the lid puncture are combined with those resulting from thermal environments as per Table 2.7-2.

Safety margins corresponding to this load combination are documented in Table 2.12-11.

The margins of safety are positive when compared to the stress intensity for each category. The most critically stressed component in the system is the lid. The minimum margins of safety are:

- +21.9 for primary membrane stress intensity on the lid center
- +3.6 for primary membrane plus bending stress intensity on the lid center
- +82.5 for primary plus secondary stress intensity on SCL C05

Figure 2.7-31 and Figure 2.7-32 show the assembly stress distribution relative to the 9-meter corner-drop, respectively cold and hot environment conditions.

Figure 2.7-33 and Figure 2.7-34 show the stress distributions in each of the structurally evaluated component for the cold environment.

[redacted]

[redacted]

[redacted]

[redacted]

2.7.3.2. Cask Side Puncture

Side puncture is evaluated analytically.

2.7.3.2.1. Minimum Wall Thickness

A series of pin puncture tests performed at Oak Ridge National Laboratory were used to develop an empirical equation for the stress in the outer wall of a multiwall cask as a function of the mass of the cask and the thickness of the cask outer wall material [Ref. 33]. This equation (Nelm's equation) is used to demonstrate pin puncture adequacy for casks with steel-lead-steel wall construction and has been the basis for the puncture analysis of several licensed casks. Solving Nelm's equation for the RT-200 outer shell:

[redacted]

Nelm's equation shows that the cask outer shell resists puncture.

2.7.3.2.2. *Cask Sidewall Bending Stresses*

The cask sidewall bending is evaluated by considering, as for the lid puncture (see Section 2.7.3.1.1.2) an impact load at a pressure of 324 MPa, i.e. the value of the pin dynamic flow stress. This value of flow stress is extracted from the true stress-strain curve for 20°C annealed mild steel in chapter 5 of "Mark's Standard Handbook for Mechanical Engineers" [Ref. 34] and corresponds to the stress required to bring approximately 5% plastic deformation in the pin.

When the cask sidewall impacts the puncture pin, the bending stress is:

$$\sigma_b = \frac{M \times c}{I} = 29.617 \text{ MPa}$$

[redacted]

The bending moment due to impact force has been calculated using the cask total length which is conservative as the portions of the total length located beneath the impact limiters and corresponding to the top and bottom forgings act with more rigidity than the rest of the cask structure. The factor of safety is:

$$FS = \frac{S_u}{\sigma_b} = \frac{462.3}{29.6} = 15.6$$

Therefore, the RT-200 cask sidewall is calculated to successfully resist the regulatory puncture drop.

2.7.3.2.3. *Lead Deformation during Side Puncture*

Following the postulated side puncture of the RT-200, the cask may experience localized deformation in the outer shell. Behind this localized deformation a slight flattening may occur, and results in shielding loss. To quantify this loss, the local stiffness of the cask wall is determined to calculate the energy absorbed by the package. To calculate the total deformation of the lead shield, it is conservatively assumed that the total available potential energy of the 1 meter puncture drop is converted to strain energy.

The maximum deformation occurs during postulated puncture event when the cask strikes the puncture probe approximately mid-span on the cask outer shell. For the purposes of this evaluation, the cask is considered a closed cylinder subjected to a concentrated load at the mid-span. The deformation is obtained from Table 13.3, case 8 of "Roark's Formulas for Stress and Strain, 7th Edition" [Ref. 23].

The deflection of the outer shell due to the applied load is:

$$y = \frac{P}{E \times t}\left[0.48 \times \left(\frac{L}{R}\right)^{0.5} \times \left(\frac{R}{t}\right)^{1.22}\right]$$

Where,

L	=	length of the cylinder
R	=	mean radius of the shell
P	=	applied load
E	=	Young's modulus
t	=	thickness of the shell

Solving for the stiffness:

$$k = \frac{P}{y} = \frac{E \times t}{0.48 \times \left(\frac{L}{R}\right)^{0.5} \times \left(\frac{R}{t}\right)^{1.22}}$$

The RT-200 is considered a composite cylinder comprised of an outer shell, lead shield, and inner shell. The resulting stiffness of each component is shown below.

2.7.3.2.3.1. Outer Shell Stiffness

[redacted]

2.7.3.2.3.2. Lead Shell Stiffness

[redacted]

[redacted]

2.7.3.2.3.3. Inner Shell Stiffness

[redacted]

2.7.3.2.3.4. Lead Deformation due to Puncture Load

The effective stiffness of the composite section of the cask is:

$$k_{eff} = k_1 + k_2 + k_3 = 8.274 \cdot 10^8\ N/m$$

The energy absorbed during impact is:

$$U = 0.5 \times k_{eff} \times \delta^2$$

Assuming the energy absorbed is equal to the total potential energy, the potential energy is calculated as:

$$E_{pot} = W \times h \times g$$

Where,

W	=	76,500 kg,	maximum gross weight of the package
h	=	1 m,	drop height for the puncture drop
g	=	9.807 m/s^{-2},	gravitational acceleration

Setting the energy absorbed during impact equal to the total potential energy the outer shell deformation is:

$$0.5 \times k_{eff} \times \delta^2 = W \times h \times g$$

$$\delta = \sqrt{\frac{W \times h \times g}{0.5 \times k_{eff}}} = 0.043\ m$$

The deformation of the lead is calculated from the ratio of the effective stiffness and lead stiffness:

$$\delta_{lead} = \delta \times \frac{k_2}{k_{eff}} = 13.0\ mm$$

Although the deformation is comprised of an elastic and inelastic component, the entire deformation is conservatively assumed to be permanent.

2.7.4. Thermal

For hypothetical accident conditions, the RT-200 cask body provides protection and containment of the contents. Thermal expansion of the bolts is evaluated to ensure the containment boundary is maintained (see RT-200 NTE 2005, Closure Bolt Evaluation [Ref. 29]). The cask body is evaluated for pressures associated with the fire accident; during the accident, the cask is assumed to be subjected to a fire that produces a surrounding environment of 800°C for a period of 30 minutes.

The capability of the cask to meet the structural requirements under the thermal accident conditions is evaluated using the same two models presented in Section 2.6.7.2:

- A 2D-axisymmetric model used for evaluation of the stresses resulting from the differential thermal expansion between dissimilar materials;
- A 3D-axisymmetric “complete” model used for evaluation of the stresses resulting from the non-thermal loads.
-

2.7.4.1. Summary of Pressures and Temperatures

Cask components temperatures under varying conditions are evaluated using the ANSYS finite element computer code [Ref. 30]. Chapter 3 provides a thermal analysis of the RT-200 when subjected to the fire accident environment of 10 CFR 71.73 [Ref. 10]. The resulting temperature distribution is used for various aspects of the structural evaluation of the RT-200 towards regulatory fire accident:

- the determination of the HAC pressure inside the cavity;
- the stress due to differential thermal expansion using the 2D-axisymmetric model described in Section 2.6.7.2.3;
- the determination of the temperature-dependent material properties to use in the numerical evaluation.

2.7.4.2. Differential Thermal Expansion

The stresses resulting from differential thermal expansion between dissimilar materials are evaluated using the same method as for the cold and hot thermal conditions of the normal conditions of transport. The temperature distribution used for the derivation of the thermal stresses is determined using the HAC fire conditions described in 10 CFR 71.73 with maximal decay heat of the radioactive material. As required by RG 7.8 [Ref. 18], the evaluations are realized 30 minutes after start of fire.

The resulting “thermal” stresses are combined with the other loads the cask is subjected to, as per Table 2.7-2 and RG 7.8 [Ref. 18].

Apart from the cask body, closure bolts may also be subjected to additional stress due to thermal expansion during fire accident. The analyses of this phenomenon are detailed in the closure bolt evaluation presented in RT-200 NTE 2005 [Ref. 29].

2.7.4.3. Stress Calculations

The following section evaluates the stresses in the bolts and cask body during hypothetical accident conditions.

2.7.4.3.1. Bolt Stresses during Fire Accident

The bolt stress evaluation is presented in [Ref. 29]. Both HAC pressure and differential thermal expansion are considered.

The evaluation shows that the bolt stresses are inferior to the allowables. Therefore, the bolts continue to provide a tight seal and containment is maintained.

2.7.4.3.2. Pressure Stress during Fire Accident

In accordance with the requirements of 10 CFR 71.73(c)(4) [Ref. 10], the RT-200 Cask is structurally evaluated when subjected to an accident internal pressure of 700 kPa (abs.).

The calculation has been performed using the 3D “complete” model presented in Section 2.6.7.2.1. The internal HAC pressure and the bolt preloads are used as boundary conditions in conjunction with displacement’s fixations on selected nodes to suppress rigid body motion.

The resulting stress intensities are combined with the thermal expansion stress intensities using the classification provided in Table 2.7-2.

2.7.4.4. Comparison with Allowable Stresses

In accordance with the requirements of 10CFR71.73 [Ref. 10], the RT-200 is structurally evaluated for the HAC fire accident.

Safety margins corresponding to this load combination are documented in Table 2.12-12. Safety margins are calculated using stress allowables derived from the material properties at the bounding temperature for the fire pressure accident.

The margins of safety are positive when compared to the stress intensity for each category. [redacted] The minimum margins of safety are:

- +49.2 for primary membrane stress intensity on SCL E02
- +35.6 for primary membrane plus bending stress intensity on SCL D17
- +2.8 for primary plus secondary stress intensity on SCL G04

Figure 2.7-35 shows the assembly stress distribution relative to the fire pressure.

Figure 2.7-36 through Figure 2.7-40 show the stress distributions in each of the structurally evaluated component.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.7.5. Immersion — Fissile Material

This Section is not applicable. The RT-200 does not have any fissile material subject to the requirements of 10 CFR 71.55 [Ref. 10].

2.7.6. Immersion — All Packages

According to the requirements of 10 CFR 71.73(c)(6) [Ref. 10], a separate, undamaged package must be subjected to an external water pressure of 150 kPa gauge a period of 8 hours. Also, 10 CFR 71.61 [Ref. 10] requires that a package's undamaged containment system should be able to withstand an external water pressure of 2,000 kPa for a period of not less than one hour without collapse, buckling or in-leakage of water. The lid is shown to be structurally adequate for a maximum external dynamic crush pressure of the top impact limiter. Therefore, the RT-200 satisfies all of the immersion requirements for a package that is used for the international shipment of radioactive materials.

2.7.7. Deep Water Immersion Test (for Type B Packages Containing More than 10^5 A2)

This Section is not applicable. The RT-200 is limited to a maximum of 3,000 A2.

2.7.8. Summary of Damage

The analytical results reported in section 2.7.1 through section 2.7.7 indicate that the damage incurred by the RT-200 during the hypothetical accident is minimal, and such damage does not diminish the cask's ability to maintain the containment boundary. A 9-meter drop or a 1-meter pin puncture accident may damage the outer shell and result in a localized reduction in shielding ability. However, the shielding remains intact to satisfy the accident shielding criteria.

Additionally, the O-rings will continue to provide positive sealing of the closure lids and cover plates during accident conditions of transport. Indeed, the maximum stress analyses performed in [Ref. 29] are based on criteria for the accident conditions intended to prevent failures by excessive plastic deformation. Using the yield stress as the stress limit for average tensile bolt stress, as per NUREG/CR- 6007 [Ref. 15], implies that a small amount of plastic deformation is permitted in the bolts. The value of this deformation is used to evaluate the minimum seal compression which, as calculated in [Ref. 29] greatly exceeds, for both the lid and the cover plates, the separation due to possible plastic deformation.

Based on the analyses of section 2.7.1 through section 2.7.7, the RT-200 fulfills the structural and shielding requirements of 10 CFR 71 [Ref. 10] for all of the hypothetical accident conditions.

2.8. ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM

This Section is not applicable. The RT-200 cask is not to be used to transport Plutonium by air.

2.9. ACCIDENT CONDITIONS FOR FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

This Section is not applicable. The RT-200 is not used to transport any fissile material by air transport.

2.10. SPECIAL FORM

This Section is not applicable. The RT-200 is not to be used to transport special form materials as specified in 10 CFR 71.75 [Ref. 10].

2.11. FUEL RODS

This Section is not applicable. The RT-200 is not to be used to transport fuel rods.

2.12. APPENDIX

This appendix contains proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390. This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

2.12.1. List of References

This paragraph provides a list of the documents that are referred to within the section 2 – “Structural Evaluation”. The detailed list of the comprehensive SAR references can be found in Section 0 – “Introduction”.

Some of the references listed below might contain proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390: when it is the case, the reference is then clearly identified "(PROPRIETARY)". This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

Ref. 10 U.S. Nuclear Regulatory Commission, 10 CFR Part 71 – Packaging and Transportation of Radioactive Material

Ref. 11 Robatel Industries, “RT-200 Transportation Package without content”, Assembly Drawing, RT-200 PC 001, Rev. D (PROPRIETARY)

Ref. 12 Robatel Industries, “RT-200 Transportation Package with content no. 1”, Assembly Drawing, RT-200 PC 002, Rev. D (PROPRIETARY)

Ref. 13 ASME Boiler & Pressure Vessel Code 2021 Edition, Section II “Materials” + Section III, Division 1 – Subsections NCD "Class 3 Components" & NF "Class support"

Ref. 14 U.S. Nuclear Regulatory Commission, Regulatory Guide 7.6, “Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels”, Revision 1, March 1978

Ref. 15 NUREG/CR-6007, “Stress Analysis of Closure Bolts for Shipping Casks”, G.C. Mok, L.E. Fisher, S. T. Hsu, Lawrence Livermore National Laboratory, Kaiser Engineering, April 1992

Ref. 16 U.S. Nuclear Regulatory Commission, Regulatory Guide 7.11, “Fracture toughness criteria of base material for ferritic steel shipping cask containment vessels with a maximum wall thickness of 4 inches (0.1 m)”, June 1991

Ref. 17 NUREG/CR-3854, “Fabrication Criteria for Shipping Container”, L. E. Fisher, W. Lai, Lawrence Livermore National Laboratory, March 1985

Ref. 18 U.S. Nuclear Regulatory Commission, Regulatory Guide 7.8, “Load combinations for the structural analysis of shipping casks for radioactive material”, Revision 1, March 1989

Ref. 19 NUREG/CR-0481, "An Assessment of Stress-Strain Data Suitable for Finite-Element Elastic-Plastic Analysis of Shipping Containers," Rack, H. & Knorovsky, G., Sandia Laboratories, Albuquerque, NM, September 1978, Retrieved on August 28, 2013

Ref. 20 ANSI N14.6-1993, “American National Standard for Special Lifting Devices for Shipping Containers Weighing 10000 pounds (4500 kg) or More for Nuclear Materials”, American National Standards Institute, Inc., 11 West 42nd Street, New York, NY

Ref. 21 Robatel Industries, “RT-200 – Handling Trunnions Calculations”, Technical Note, RT-200 NTE 2002, Rev. C (PROPRIETARY)

Ref. 22 Oberg, Jones, Horton Ryffel, “Machinery’s Handbook”, 27th Edition

Ref. 23 Young, Budynas, “Roark’s formulas for stress and strain”, 7th edition

Ref. 24 Robatel Industries, “RT-200 – Tie-Down Calculations”, Technical Note, RT-200 NTE 2003, Rev. C (PROPRIETARY)

Ref. 25 Robatel Industries, “RT-200 – Drops Calculations”, Technical Note, RT-200 NTE 2101, Rev. B (PROPRIETARY)

Ref. 26 Robatel Industries, “RT-200 – Cask Body Calculations”, Technical Note, RT-200 NTE 2004, Rev. B (PROPRIETARY)

Ref. 27 Robatel Industries, “RT-200 – Material Mechanical Properties”, Technical Note, RT-200 NTE 2001, Rev. C (PROPRIETARY)

Ref. 28 NUREG/CR-0128, “Shock and Vibration Environments for a Large Shipping Container During Truck Transport’, Clifford F. Magnuson, Sandia Laboratories, Albuquerque, NM, May 1978

Ref. 29 Robatel Industries, “RT-200 – Closure Bolt Evaluation”, Technical Note, RT-200 NTE 2005, Rev. B (PROPRIETARY)

Ref. 30 ANSYS, Release 21.2, ANSYS Inc., Canonsburg, PA, October 2011

Ref. 31 SOLIDWORKS, Release 2022, DASSAULT Systèmes, Vélizy-Villacoublay, France

Ref. 32 Robatel Industries, “RT-200 – Pressures Calculations”, Technical Note, RT-200 NTE 3003, Rev. C (PROPRIETARY)

Ref. 33 ORNL/M-5003, “The Radioactive Materials Packaging Handbook”, 1988, Oak Ridge, Tennessee, Oak Ridge National Laboratory

Ref. 34 Avallone, Baumeister III, “Mark’s Standard Handbook for Mechanical Engineers”, 10th Edition

2.12.2. Material Mechanical Properties Tables

The mechanical properties summarized in the tables below come from various data sources that are documented and presented in the technical note RT-200 NTE 2001 [Ref. 27].

Table 2.12-1 Cask Temperature-Dependent Metallic Material Properties

[redacted]

[redacted]

Table 2.12-2 Cask Temperature-Independent Metallic Material Properties

[redacted]

Table 2.12-3 Foam Crush Strength Parameters

[redacted]

2.12.3. Fatigue Analysis

This appendix presents the fatigue analysis performed on the following RT-200 cask components:

- The impact limiter's tightening bolts, used during transport;
- The lid's threads, which are used for both the lid's lifting operations and the front impact limiter's fixation. The bottom forging is also fitted with similar threads for the fixation of the rear impact limiter, but since the lid's threads are also used for the lid's lifting, they are subjected to a more significant fatigue stress. Thus, the demonstration of the lid's threads' capability to resist fatigue failure is sufficient to demonstrate the fatigue resistance of the bottom forging's threads;
- The welded trunnions, which are used for both the cask's tie-down on the transport frame and the cask body lifting;
- The bolted trunnions, which are used for the cask body lifting;
- The impact limiter's lifting belt, which is used for the impact limiter's lifting ;
- The closure bolts, which are used for the closing of both the lid and the cover plates during transport.

2.12.3.1. Analysis Method

The fatigue analysis is conducted in accordance with the procedures provided in Appendix XIII-4230(b) and XIII-3520 of ASME III [Ref. 13]. Accordingly, the fatigue analysis is completed for normal conditions of transport using:

- fatigue strength reduction factor to account for local discontinuities.
- fatigue curves I-9-2 and I-9.4 (from ASME III - Appendix I) with elastic modulus adjustment.

The loads due to the vibration normally incident to transport are derived from the vibration accelerations the cask is subjected to during transport. The highest levels of input vibrations are given in Section 2.6.5 and resumed here:

- A longitudinal acceleration of 0.27 g
- A transverse acceleration of 0.19 g
- A vertical acceleration of 0.52 g

The loads due to the lifting of specific components are determined using the same methods as in RT-200 NTE 2002 [Ref. 21], which details the cask body lifting load calculations.

2.12.3.2. Fatigue Analysis of the Impact Limiter's Tightening Bolts

The impact limiter's tightening bolts are subjected to the vibration loads normally incident to transport. The tensile force applied on each impact limiter's tightening bolt equals:

[redacted]

Using the value of the tensile force and the tensile-stress area of an M42 screw thread calculated in Section 2.5.1.2.2, the tensile stress can be derived as follows:

$$\sigma = \frac{F_{t.IL}}{A_t} = 1.1\ \mathrm{MPa}$$

Where,

A_t = 1,009.4 mm2, tensile-stress area of M42 bolts

As per ASME XIII-2410, the corresponding alternating stress intensity S_{alt} equals:

$$S_{alt} = \frac{1}{2}\sigma = 0.6\ \mathrm{MPa}$$

To account for local structural discontinuities, a fatigue reduction factor (RF) of 5 is applied. In addition, since the bolting material elastic modulus used in the analysis is not the same as the one given on the design fatigue curves, the alternating stress is multiplied by the moduli ratio. Follows the alternating stress intensity to use in the ASME fatigue curves:

$$S_{alt.curve} = RF \times \frac{E_{ref}}{E_{bolt}} \times S_{alt} = 3\ \mathrm{MPa}$$

Where,

RF	=	5,	strength reduction factor (Appendix XIII-3520(b))
E_{ref}	=	207 GPa,	modulus of elasticity on ASME design fatigue curve of Figure I-9.4
E_{bolt}	=	197 GPa,	modulus of elasticity of the bolting material at 80°C

Using the calculated alternating stress intensity and the fatigue curve for a maximum nominal stress ≤ 2.7 Sm in ASME Section III, Figure I-9.4, it can be shown that the stress in the bolts is well below the endurance limit of the bolting material. Therefore, the impact limiter's tightening bolts are not subjected to fatigue damage.

2.12.3.3. Fatigue Analysis of the Lid's Threads

The lid's threads are subjected to two cyclic loads:

- The vibration loads normally incident to transport;
- The lid's lifting loads during handling operations.

2.12.3.3.1. Transport Vibration Load Cycle

The loads due to the vibration normally incident to transport are derived from the tensile force $F_{t.IL}$ used in the fatigue analysis of the tightening bolts. The stress in the lid's threads is calculated using the shear-stress area of M42 internal threads determined in Section 2.5.1.2.2.2:

$$\sigma = \frac{F_{t.IL}}{A_n} = 0.4 \text{ MPa}$$

Where,

A_n = 2,922.1 mm^2, shear-stress area of the lid's internal thread

The corresponding alternating stress intensity S_{alt} equals:

$$S_{alt} = \frac{1}{2}\sigma = 0.2 \text{ MPa}$$

Follows the alternating stress intensity to use in the ASME fatigue curves:

$$S_{alt.curve} = RF \times \frac{E_{ref}}{E_{lid}} \times S_{alt} = 1.1 \text{ MPa}$$

Where,

E_{lid} = 190.6 GPa, modulus of elasticity of the lid's material at 80°C
E_{ref} = 195 GPa, modulus of elasticity on design fatigue curve of Figure I-9-2
All other terms are as previously defined.

Using the calculated alternating stress intensity and the fatigue curve in ASME Section III, Figure I-9.2, it can be shown that the stress in the thread is well below the endurance limit of the lid's material. Therefore, the vibration load cycle the lid's threads are subjected to doesn't lead to fatigue damage.

2.12.3.3.2. Lid Lifting Load Cycle

The lifting load used for the fatigue analysis of the lid's threads is derived from Section 2.5.1.2.2. The stress in the lid's threads is calculated as follows:

$$\sigma = \frac{F_{lr}}{A_n} = 2.7 \text{ MPa}$$

Where,

F_{lr} = 7.8 kN, lifting load on one thread
All other terms are as previously defined.

The corresponding alternating stress intensity S_{alt} equals:

$$S_{alt} = \frac{1}{2}\sigma = 1.3 \text{ MPa}$$

Follows the alternating stress intensity to use in the ASME fatigue curves:

$$S_{alt.curve} = RF \times \frac{E_{ref}}{E_{lid}} \times S_{alt} = 6.9 \text{ MPa}$$

Where,

E_{lid} = 190.6 GPa, modulus of elasticity of the lid's material at 80°C
E_{ref} = 195 GPa, modulus of elasticity on design fatigue curve of Figure I-9-2
All other terms are as previously defined.

Using the calculated alternating stress intensity and the fatigue curve in ASME Section III, Figure I-9.2, it can be shown that the stress in the thread is below the endurance limit of the lid's material. Therefore, the lifting load cycle the lid's threads are subjected to doesn't lead to fatigue damage.

2.12.3.4. Fatigue Analysis of the Welded Trunnions

The welded trunnions are subjected to two cyclic loads:

- The vibration loads normally incident to transport;
- The lifting loads during handling operations (only the rear trunnions).

2.12.3.4.1. Transport Vibration Load Cycle

The welded trunnions are evaluated for fatigue for the vibration loads normally incident to transport. To determine these loads, the calculation procedure described in Section 2.12.3.2 has been followed, using the vibrational accelerations cited in Section 2.6.5.

This leads to the following loads:

$$F_v = 108.2 \text{ kN}$$

$$F_l = 50.6 \text{ kN}$$

$$F_h = 79.1 \text{ kN}$$

Where,

F_v	=	108.2 kN,	vertical force on the trunnion
F_l	=	50.6 kN,	longitudinal force on the trunnion
F_t	=	79.1 kN,	transverse force on the trunnion

Following the same procedure as in RT-200 NTE 2003 [Ref. 24], the maximum local equivalent stress at the base junction of the trunnion (taking into account local discontinuities) is:

$$\sigma_t = 5 \text{ MPa}$$

Regarding the weld, the total Von-Mises equivalent stress within the most stressed weld section equals:

$$\sigma_w = 7.5 \text{ MPa}$$

The corresponding alternating stress intensities equal:

$$S_{alt.t} = \frac{1}{2}\sigma_t = 2.5 \text{ MPa}$$

$$S_{alt.w} = \frac{1}{2}\sigma_w = 3.75 \text{ MPa}$$

The alternating stress intensities to use with the ASME fatigue curves equal:

$$S_{alt.curve.t} = \frac{E_{ref}}{E_{trunnion}} \times S_{alt} = 2.5 \text{ MPa}$$

$$S_{alt.curve.w} = RF \times \frac{E_{ref}}{E_{weld}} \times S_{alt} = 19.1 \text{ MPa}$$

Where,

$E_{trunnion}$ = 190.6 GPa, modulus of elasticity of the welded trunnion's material at 80°C
E_{weld} = 190.6 GPa, modulus of elasticity of the weld at 80°C
E_{ref} = 195 GPa, modulus of elasticity on design fatigue curve of Figure I-9-2
All other terms are as previously defined.
No concentration factor is needed for the alternating stress intensity of the trunnion since a concentration factor has already been considered in the stress evaluation.

Using the calculated alternating stress intensities and the fatigue curve in ASME Section III, Figure I-9.2, it can be shown that the stresses in the trunnion and in the weld are below the endurance limit of the trunnion's material. Therefore, the vibration load cycle the welded trunnions are subjected to during transport doesn't lead to fatigue damage.

2.12.3.4.2. Lifting Load Cycle

The welded trunnions are evaluated for fatigue for the lifting loads. To determine these loads, the calculation procedure described in Section 2.5.1.2.1 has been followed..

This leads to the following loads:

$$F_T = 190.7 \text{ kN}$$

$$F_W = 71.9 \text{ kN}$$

Where,

F_T = 190.7 kN, maximum load applied on one trunnion
F_W = 71.9 kN, shear load generated by the friction of the contact on the weld

Following the same procedure as in RT-200 NTE 2002 [Ref. 21], the maximum local equivalent stress at the base junction of the trunnion (taking into account local discontinuities) is:

$$\sigma_t = 7.9 \text{ MPa}$$

Regarding the weld, the total Von-Mises equivalent stress within the most stressed weld section equals:

$$\sigma_w = 19.5 \text{ MPa}$$

The corresponding alternating stress intensities equal:

$$S_{alt.t} = \frac{1}{2}\sigma_t = 4 \text{ MPa}$$

$$S_{alt.w} = \frac{1}{2}\sigma_w = 9.8 \text{ MPa}$$

The alternating stress intensities to use with the ASME fatigue curves equal:

$$S_{alt.curve.t} = \frac{E_{ref}}{E_{trunnion}} \times S_{alt} = 4.1 \text{ MPa}$$

$$S_{alt.curve.w} = RF \times \frac{E_{ref}}{E_{weld}} \times S_{alt} = 50.0 \text{ MPa}$$

Where,

$E_{trunnion}$	=	190.6 GPa,	modulus of elasticity of the welded trunnion's material at 80°C
E_{weld}	=	190.6 GPa,	modulus of elasticity of the weld at 80°C
E_{ref}	=	195 GPa,	modulus of elasticity on design fatigue curve of Figure I-9-2

All other terms are as previously defined.

No concentration factor is needed for the alternating stress intensity of the trunnion since a concentration factor has already been considered in the stress evaluation.

Using the calculated alternating stress intensities and the fatigue curve in ASME Section III, Figure I-9.2, it can be shown that the stresses in the trunnion and in the weld are below the endurance limit of the trunnion's material. Therefore, the lifting load cycle the welded trunnions are subjected to doesn't lead to fatigue damage.

2.12.3.5. Fatigue Analysis of the Bolted Trunnions

The bolted trunnions are evaluated for fatigue for the loads produced by the cask lifting operations. The stress generated during lifting in the two lifting trunnions is calculated using the same procedure as in RT-200 NTE 2002 [Ref. 21], but without considering the γ_y and γ_u stress design factors. The stress due to lifting is used to determine the alternating stress intensity:

$$S_{alt.t} = \frac{1}{2}\sigma = 19.2 \text{ MPa}$$

Where,

σ	=	77 MPa,	maximum local equivalent stress at the base junction of the trunnion (taking into account local discontinuities)

The alternating stress intensity to use in the ASME fatigue curves equals:

$$S_{alt.curve} = \frac{E_{ref}}{E_{trunnion}} \times S_{alt} = 19.7 \text{ MPa}$$

Where,

$E_{trunnion}$	=	190.6 GPa,	modulus of elasticity of the welded trunnion's material
E_{ref}	=	195 GPa,	modulus of elasticity on design fatigue curve of Figure I-9-2

Using the calculated alternating stress intensity and the fatigue curve for austenitic steels in ASME Section III, Figure I-9.2, it can be shown that the stress in the trunnion is below the endurance limit of the trunnion's material. Therefore, the lifting load cycle the bolted trunnions are subjected to during lifting operation doesn't lead to fatigue damage.

2.12.3.6. Fatigue Analysis of the Impact Limiter's Lifting Attachment

The impact limiter's lifting belt is evaluated for fatigue for the loads produced by the lifting operations. The stresses generated during lifting are calculated using the same procedure as in Section 2.5.1.2.3, but without considering the γ_y and γ_u stress design factors. The latter stresses are used to determine the alternating stress intensity:

$$S_{alt} = \frac{1}{2}\sigma_{max} = 9.3 \text{ MPa}$$

Where,

σ_{max} = 18.5 MPa, maximum local equivalent stress at the base of the lifting belt's eye (taking into account local discontinuities)

The alternating stress intensity to use in the ASME fatigue curves equals:

$$S_{alt.curve} = \frac{E_{ref}}{E_{IL}} \times S_{alt} = 9.5 \text{ MPa}$$

Where,

E_{IL} = 190.6 GPa, modulus of elasticity of the lifting attachment material
E_{ref} = 195 GPa, modulus of elasticity on design fatigue curve of Figure I-9-2

Using the calculated alternating stress intensities and the fatigue curve in ASME Section III, Figure I-9.2, it can be shown that the stress in the lifting attachment is below the endurance limit of the device's material. Therefore, the lifting load cycle the impact limiter's lifting attachment is subjected to during lifting operation doesn't lead to fatigue damage.

2.12.3.7. Fatigue Analysis of the Closure Bolts

The various values of stress used in the calculations of this section are extracted from [Ref. 29] and have been obtained by following the procedure specified in NUREG/CR-6007 [Ref. 15].

2.12.3.7.1. Fatigue Analysis of the Closure Lid Bolts

Fatigue of the closure lid bolts due to operating loads is documented based on the maximum NCT cases. The direct stress is obtained by combining the axial and bending stresses. The shear stress is obtained by combining the average shear load and torsional bolt moment. One principal stress is zero and the remaining two are calculated from the combined direct and shear stress by:

$$S_p = \frac{\sigma}{2} \pm \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} = 329.7 \text{ MPa}$$

Where,

σ	=	324.4 MPa
τ	=	41.6 MPa

The corresponding alternating stress intensity equals:

$$S_{alt} = \frac{1}{2} S_p = 164.8 \text{ MPa}$$

To account for local structural discontinuities, a fatigue reduction factor (RF) of 4 is applied. In addition, since the bolting material elastic modulus used in the analysis is not the same as the one given on the design fatigue curves, the alternating stress is multiplied by the modulus ratio.

Follows the alternating stress intensity to use in the ASME fatigue curves:

$$S_{alt\_curve} = RF \times \frac{E_{ref}}{E_{bolt}} \times S_{alt} = 692.8 \text{ MPa}$$

Where,

RF	=	4,	Fatigue strength reduction factor, given in Table 6.2 of [Ref. 15]
E_{ref}	=	207 Gpa,	Modulus of elasticity on ASME design fatigue curve of Figure I-9.4
E_{bolt}	=	197 GPa,	Modulus of elasticity of the bolt material at 80°C

Using the alternating stress intensity calculated and the fatigue curve for a maximum nominal stress ≤ 2.7 Sm in ASME Section III, Figure I-9.4 [Ref. 13], the corresponding fatigue limits are calculated by interpolating the tabular data given in ASME Section III, Table I-9.0M, [Ref. 13]. The estimated allowable number of cycles, N, for the 692.8 MPa alternating stress is 989 cycles.
The acceptance criteria regarding the fatigue analysis requires the real number of load cycles to be lower than the allowable number of cycles. Thus, the real number of cycles must be inferior to 989.
Considering that the repeated preload is the worst load, Table 6.2 of [Ref. 15] suggests that the latter should be used to determine the allowable life of the closure bolts.

2.12.3.7.2. Fatigue Analysis of the Cover Plate Bolts

Fatigue of the cover plate bolts due to operating loads is documented based on the maximum NCT cases. The direct stress is obtained by combining the axial and bending stresses. The shear stress is obtained by combining the average shear load and torsional bolt moment. One principal stress is zero and the remaining two are calculated from the combined direct and shear stress by:

$$S_p = \frac{\sigma}{2} \pm \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} = 375.7\ \mathrm{MPa}$$

Where,

σ	=	362.9 Mpa
τ	=	69.6 MPa

The corresponding alternating stress intensity equals:

$$S_{alt} = \frac{1}{2} S_p = 187.9\ \mathrm{MPa}$$

To account for local structural discontinuities, a fatigue reduction factor (RF) of 4 is applied. In addition, since the bolting material elastic modulus used in the analysis is not the same as the one given on the design fatigue curves, the alternating stress is multiplied by the modulus ratio.

Follows the alternating stress intensity to use in the ASME fatigue curves:

$$S_{alt\_curve} = RF \times \frac{E_{ref}}{E_{bolt}} \times S_{alt} = 789.6\ \mathrm{Mpa}$$

Where,

RF	=	4,	Fatigue strength reduction factor, given in Table 6.2 of [Ref. 15]
E_{ref}	=	207 Gpa,	Modulus of elasticity on ASME design fatigue curve of Figure I-9.4
E_{bolt}	=	197 GPa,	Modulus of elasticity of the bolt material at 80°C

Using the alternating stress intensity calculated and the fatigue curve for a maximum nominal stress ≤ 2.7 Sm in ASME Section III, Figure I-9.4 [Ref. 13], the corresponding fatigue limits are calculated by interpolating the tabular data given in ASME Section III, Table I-9.0M, [Ref. 13]. The estimated allowable number of cycles, N, for the 789.6 MPa alternating stress is 768 cycles.

The acceptance criteria regarding the fatigue analysis requires the real number of load cycles to be lower than the allowable number of cycles. Thus, the real number of cycles must be inferior to 768.

Considering that the repeated preload is the worst load, Table 6.2 of [Ref. 15] suggests that the latter should be used to determine the allowable life of the closure bolts.

2.12.4. Lifting Attachment Figures

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.12.5. Basket Buckling Analysis

The design of the RT-200 cask basket has been evaluated for buckling. This evaluation has been realized following the guidance provided by the ASME B&PV Code, Section III, Subsection NF [Ref. 13]. As shown in Figure 2.12-7, the basket is a column made of a cylindrical shell, to which guide discs hollowed out by the external shape of the disposable insert are welded at each end.

[redacted]

The five guidance discs located inside of the basket cylindrical shell allow to prevent lateral buckling of the basket. Therefore, only axial buckling of the basket is analyzed.
The end drop is the most penalizing configuration for the basket buckling, since it is where the axial compressive force applied to the cylindrical shell is at its maximum.

The guidance disks are not considered in the buckling analysis of the basket. This adds conservatism to the evaluation, as these disks significantly reinforce the overall stiffness of the basket, since they block the radial displacement of the cylindrical shell at several points.

The ASME B&PV Code, Section III, Subsection NF, Article NF-3223.5 [Ref. 13] provides a guidance for the calculation of the buckling stress limit for the special case of “Cylindrical Shells Under Axial Compression”. Following this guidance, the allowable compressive stress to be used equals:

$$\sigma_{cr} = \min(S_m, B) = 94 \text{ MPa}$$

Where,

S_m = 115 MPa, design stress intensity (determined in ASME Section II, Part D, Subpart 1)
B = 94 MPa, maximum allowable compressive stress (determined from the applicable chart contained in ASME Section II, Part D, Subpart 3)

The value of B is determined using the factor A calculated as follows:

[redacted]

The value of factor A is reported in the chart presented in Figure HA-3 of ASME Section II, Part D, Subpart 3 [Ref. 13] for a material/temperature line of 80°C (bounding temperature value of the inner shell, see Chapter 3). The corresponding value of B is 94 MPa.

During an end-drop, one end of the basket rests on the internal cavity, while the other end, due to the inertial forces, presses down the cylindrical shell.

Since the upper end of the basket is heavier than the lower end, the most penalizing case regarding the basket compression is the 9 m end-drop on the bottom forging. The compression force applied by the upper end of the basket on the cylindrical shell equals:

$$F = M_{ue} \times a_{ED}$$

Where,

M_{ue} = 841 kg, mass of the basket upper end (850 kg used)
a_{ED} = 88 g, cask deceleration during 9m end drop (value extracted from [Ref. 25])

Thus,

$$F = 734 \text{ kN}$$

The compressive stress in the cylindrical shell equals:

$$\sigma = \frac{F}{S}$$

Where,

S = 27,908 mm², minimal cross section of the cylindrical shell (determined by considering the radial holes in the shell)

Thus,

$$\sigma = 26.3 \text{ MPa}$$

The safety factor towards basket buckling is thus:

$$FS = \frac{\sigma_{cr}}{\sigma} = 3.57 > 1$$

Therefore, no buckling instability will occur in the basket when the cask is subjected to the regulatory conditions of 10 CFR 71 [Ref. 10] and the basket design is compliant with the regulatory requirements which state that buckling must be precluded.

2.12.6. 9-meter End-Drop Evaluation

The evaluation of the 9-meter end-drop aims to provide the values of the impact forces and g-loads the RT-200 cask is subjected to for the 9-meter end-drop. This section's purpose is to present, as an example, the method, formulas and analyses performed on this particular drop configuration, knowing that the same methodology has been followed for all the other drop configurations.

In particular, the calculations must provide:

- The values of the impact force of the ground on the impact limiter and the cask deceleration;
- The crush depth;
- The initial temperature conditions that lead to the highest loads to be applied on the cask;
- The dissipated energy during the crush.

The principles and methods employed to gather the previously described results in the 9-meter end drop configuration are presented hereunder.

2.12.6.1. Impact Behavior Description

When the RT-200 is dropped, the potential energy associated with the height will gradually reduce and will be converted to kinetic energy at the point of impact.

At impact, the kinetic energy is maximum. From that moment, the impact limiter starts to crush and the kinetic energy of the cask assembly starts to dissipate until the cask stops. In reality, the cask and the ground are not perfectly rigid structures and dissipate a small portion of the energy. This reduces the energy required to be absorbed by the impact limiters. Thus, it is conservative to neglect the energy absorbed by the cask and ground when calculating impact limiter performance.

During impact, the cask assembly is subjected to two forces: its weight and the impact limiter's crush force. The latter is a function that depends on several factors (crush depth, foam mechanical behavior, impact limiter geometry). At the beginning of the impact, the crush depth is low and only a small portion of the foam is being deformed. This results in force values which are low in relation to the weight of the packaging, and which therefore have no influence on the kinematics of the drop. But as the impact limiter goes deeper into the ground, both the deformation of the foam and the contact surface with the ground increase, leading to an ever-increasing force opposing the weight of the package. Once this force exceeds the value of gravity, the cask gets progressively more decelerated and its vertical speed at impact point gradually reduces to zero.

2.12.6.2. Solving Method

This section describes the solving processes used to perform the drop analyses in each drop case.

2.12.6.2.1. <u>Initial Conditions Calculations</u>

The initial potential energy of the cask is calculated as follows:

$$E_P = E_k = m \times g \times h$$

Where:

E_P = potential energy at initial height
E_k = kinetic energy at point of impact
m = maximal mass of cask assembly
g = gravity acceleration
h = drop height

Using the energy principle and, considering that the initial potential energy is completely converted to kinetic energy, the following formula gives the vertical speed at the impact point:

$$v_{impact} = \sqrt{2gh}$$

All terms were previously defined.

The other initial conditions are known and can be set without calculation.

2.12.6.2.2. Numerical Integration

Time history results of dissipated energy, deceleration, velocity, and crush depth are calculated using numerical integration methods.

The crush force corresponds to the reaction force of the ground on the cask assembly. It is calculated at each step of the numerical integration using the crush depth, the geometric parameters of the impact limiter, the foam mechanical behavior and the parameters and conditions of the drop case.

The dissipated energy during an impact corresponds to the work of the crushing force through the impact crush depth. Based on the energy principle, the overall initially available energy should be equal to the dissipated energy.
Thus,

$$E_{diss} = \int F(x_c)dx_c = mg(h + x_{c.tot})$$

Where :

x_c = crush depth
$F(x_c)$ = crush force
$x_{c.tot}$ = total crush depth
All the other terms were previously defined.

As shown in the previous formula, the energy dissipated during impact is greater than the potential energy available when the cask is released. This is due to the second term, which corresponds to the work of the weight as the cask sinks into the ground.

2.12.6.2.3. Application to the End-drop Case

Figure 2.12-8 shows the cask configuration when the impact limiter initiates contact with the ground surface.

[redacted]

As the foam gradually deforms, the amount of dissipated energy increases and the remaining kinetic energy is reduced based on the energy conservation principle. Figure 2.12-9 shows the cask configuration when the kinetic energy becomes zero (vertical velocity = 0 m/s).

[redacted]

[redacted]

[redacted]

[redacted]

The crush strength associated with the specific strain is determined from the material properties provided in Section 2.2.1 of this SAR. Impact limiter crush load F_{IL} can be determined from the calculated contact areas and the corresponding crush strength as follows:

[redacted]

Based on the general principle defined in Section 2.12.6.2.2, numerical integration is performed to obtain time evolution of the reaction force, vertical deceleration (g-load), dissipated energy and foam displacement.

[redacted]

The numerical integration is continued until the velocity dz reaches zero i.e., when the impact limiter's crushing stops. The results (maximal crush depth and impact force) are then used in the cask body calculations as input data for the boundary conditions.

As an example, the four following figures show time history results for a temperature of 38°C using the minimal crush strength-strain behavior:

- Figure 2.12-11 shows crush force results;
- Figure 2.12-12 shows dissipated energy results;
- Figure 2.12-13 shows velocity results;
- Figure 2.12-14 shows crush depth results.

In this case, the crush force and depth reach respectively 56.1 MN and 234.2 mm in 29 ms. As shown in Figure 2.12-12 and Figure 2.12-13, the initial kinetic energy is dissipated due to foam crushing and velocity reaches zero at the end of impact.

All results for all the drop configurations are shown in detail and discussed in [Ref. 25].

[redacted]

[redacted]

[redacted]

[redacted]

2.12.7. NCT Result Tables

The following tables provide for each one of the Normal Conditions of Transport load combinations the resulting safety margins for each of the stress classification lines and for all the evaluated classified stress intensities.

The safety margin is calculated using the following formula:

$$Safety\ Margin = \frac{Allowable\ Stress\ Intensity}{Calculated\ Stress\ Intensity} - 1$$

Thus, for a given classified stress intensity and a given stress classification line, the design criteria is considered to be fulfilled if the safety margin is positive.

Eventually, in the following tables, each displayed safety margin corresponds to the minimal value of safety margin calculated between the various environmental conditions for the given drop configuration.

Table 2.12-4 NCT End Drop Safety Margins

[redacted]

[redacted]

[redacted]

[redacted]

Table 2.12-5 NCT Side Drop Safety Margins

[redacted]

[redacted]

[redacted]

[redacted]

Table 2.12-6 NCT Corner Drop Safety Margins

[redacted]

[redacted]

[redacted]

[redacted]

2.12.8. HAC Result Tables

The following tables provide for each one of the Hypothetic Accident Conditions of Transport load combinations the resulting safety margins for each of the stress classification lines and for all the evaluated classified stress intensities.

The safety margin is calculated using the following formula:

$$Safety\ Margin = \frac{Allowable\ Stress\ Intensity}{Calculated\ Stress\ Intensity} - 1$$

Thus, for a given classified stress intensity and a given stress classification line, the design criteria is considered to be fulfilled if the safety margin is positive.

Eventually, in the following tables, each displayed safety margin corresponds to the minimal value of safety margin calculated between the various environmental conditions for the given drop configuration.

Table 2.12-7 HAC End Drop Safety Margins

[redacted]

[redacted]

[redacted]

[redacted]

Table 2.12-8 HAC Side Drop Safety Margins

[redacted]

[redacted]

[redacted]

[redacted]

Table 2.12-9 HAC Corner Drop Safety Margins

[redacted]

[redacted]

[redacted]

[redacted]

Table 2.12-10 HAC Slap Down Drop Safety Margins

[redacted]

[redacted]

[redacted]

[redacted]

Table 2.12-11 HAC Lid Puncture Safety Margins

[redacted]

Table 2.12-12 HAC Fire Pressure Safety Margins

[redacted]

[redacted]

[redacted]

[redacted]

3. THERMAL EVALUATION

Robatel has performed a thermal evaluation of the RT-200 using the Nuclear Industry standards and under the RT Quality Assurance Program [Ref. 35]. This thermal evaluation shows that the RT-200 meets or exceeds all the 10 CFR 71 regulatory requirements [Ref. 36]. The thermal review is based in part on the descriptions and evaluations presented in the General Information Chapter 1 and Structural Evaluation Chapter 2 of the application. Similarly, results of the thermal review are considered in the review of several other sections of the application.

Robatel identified, described, discussed, and analyzed the principal thermal engineering design of the RT-200, components, and systems that are important to safety. Section 3 describes how the package complies with the performance requirements of 10 CFR 71 [Ref. 36]. Results of the thermal evaluation verified that the thermal performance of the RT-200 design (for both NCT and HAC) meets the thermal regulatory requirements as follows:

- The RT-200 design is evaluated to demonstrate that it satisfies the thermal requirements of 10 CFR 71.31(a)(1); 10 CFR 71.31(a)(2); 10 CFR 71.33, and 10 CFR 71.35(a) [Ref. 36].
- The application identifies the established codes and standards used for the thermal design according to 10 CFR 71.31(c) [Ref. 36].
- The performance of the RT-200 is evaluated under the tests specified in 10 CFR 71.71 for NCT and 10 CFR 71.73 for HAC and also references 10 CFR 71.41(a) [Ref. 36].
- The RT-200 is designed, constructed, and prepared for transport so that there is no significant decrease in packaging effectiveness under the tests specified in 10 CFR 71.71 (NCT) and references in 10 CFR 71.43(f) and 71.51(a)(1) [Ref. 36].
- The RT-200 is designed, constructed, and prepared for transport so that the accessible surface temperature does not exceed the regulatory limits specified in 10 CFR 71.43(g) [Ref. 36].
- The RT-200 design does not rely on mechanical cooling systems to meet containment requirements in reference to 10 CFR 71.51(c) [Ref. 36].
- The RT-200 has adequate thermal performance to meet the containment, shielding, sub-criticality, and temperature requirements of 10 CFR 71 [Ref. 36] for (NCT/HAC).

Table of Content

3.1. DESCRIPTION OF THERMAL DESIGN

The thermal design aspects of the RT-200 are related primarily to protecting the sensitive components of the cask and the contents from the elevated temperatures produced by the hypothetical fire accident. The primary thermal criteria that are applied to the thermal evaluation are maintaining the lead shielding in the cask body below the melting temperature of lead and the maximum temperature of the O-ring seals below their maximum operating temperature. The components primarily responsible for maintaining the temperatures of these components below their acceptance criteria are the impact limiters covering the front and rear of the cask and the thermal shield on the radial cask surface.

The impact limiters are made from a foam material, as detailed in Chapter 8, Section 8.1.5.1, that has a low thermal conductivity. The impact limiters cover the front and rear ends of the cask. They protect the O-rings in the lid and the vent and drain ports cover plates. The impact limiters are designed to remain attached to the cask during normal operations and hypothetical accident conditions, and to insulate the O-rings from the high temperatures of the hypothetical fire accident. The thermal shield covering the radial cask surface is made of a ceramic fiber material with a very low thermal conductivity. The ceramic fiber is covered by a thin, stainless-steel cover that protects it from damage during normal handling. The ceramic fiber material is designed for use in insulating refractory furnaces and provides an excellent thermal barrier for the fire accident, thus preventing the radial lead from exceeding its melting point.

3.1.1. Design Features

As briefly described in Section 3.1, the RT-200 design has two primary thermal design features: the impact limiters and the radial thermal shield. These features are identified in Chapter 1, Figure 1.2-1 which highlights the primary components of the cask.

3.1.1.1. RT-200 Description

The RT-200 cask body consists of inner and outer shells constructed of stainless-steel. Lead shielding is provided between these radial shells. The front of the cask comprises the front stainless-steel forging that is attached to the inner and outer shells, and contains the mating surface for the lid. The lid is constructed of stainless-steel, as are the vent and drain port cover plates. The lid is attached using thirty (30) M42 round head hex bolts. The front and rear impact limiters cover each end of the cask, and are constructed of stainless-steel shells containing foam blocks. The impact limiters are secured to the cask via eight (8) M42 round head hex bolts. The RT-200 is described in greater detail in Chapter 1, Section 1.2.1.

Most of the outer shell of the cask is covered by a ceramic fiber thermal shield that is secured by a thin stainless-steel cover, except for the four welded trunnion areas also made of stainless-steel.

3.1.1.2. Dimensions

The RT-200 thermal analysis is performed using the basic cask dimensions as presented in Appendix 1.3.2. Tolerances on the metallic part thicknesses have a negligible influence on the results, mainly because temperature gradients are localized in the less conductive materials (foam, ceramic paper and air gaps).

In NCT, the nominal thickness of the impact limiters is used. Tolerances on this thickness will have no significant impact on the results due to the nearly perfect insulation created by the amount of foam. However, in the “thermal” HAC calculation, for conservatism, the foam thickness is reduced by almost 90% to just 30 mm, which accounts for both the crush depth of the HAC drops as well as manufacturing tolerances.

The ceramic paper, as detailed in Chapter 8, Section 8.1.5.3 used to protect the cask body is represented by its nominal thickness. For conservatism, its thermal conductivity coefficient is divided by 1.5 in NCT cases and multiplied by 1.5 in HAC cases to take credit for tolerances on thickness and conductivity. This is equivalent to increasing the ceramic paper thickness by a factor 1.5 in NCT and reducing it by the same factor in HAC. This increases the thermal insulation in NCT and then increases the inner temperature of the cask, and reduces the thermal protection in HAC, and then increases the heat transfer from the fire to the cask.

The air gaps between the impact limiters and the cask body, between the lid and the cask body, between the lead and the outer shell, between the central lead parts, the front and rear lead parts are also modeled at their nominal value. However, in the HAC case, the air thermal conductance in gaps between the lead and the outer shell and between the impact limiters and the body is multiplied by 10 for conservatism. This is equivalent to reducing the gaps by a factor of 10. Those assumptions are penalizing as they maximize the heat transfer from the fire to the cask components.

3.1.2. Content’s Decay Heat

The maximal internal decay heat used in all cases is 1,200 W for the whole content. It is applied on the cask cavity surface as a uniform heat flux (see sections 1.2.2.1.9 and 1.2.2.2.9).

This low decay heat value does not produce a significant temperature gradient through the cask body, and as a result, no specific design features are required to facilitate removing the heat from the cavity.

3.1.3. Summary Tables of Temperatures

Section 3.1.3 presents summary tables of maximum temperatures occurring in the RT-200 as a result of the NCT and HAC evaluations described in detail in Sections 3.3 and 3.4. Limiting temperatures for consideration in the structural and containment evaluations are the maximum temperatures. Therefore, the following tables present maximum temperatures that occur in the various cask components under NCT and HAC. Table 3.1-1 presents the NCT maximum temperatures while Table 3.1-2 presents the HAC maximum temperatures. For the fire accident evaluation, the time at which the component reaches its maximum temperature is listed along with the temperature in Figure 3.4-1 (see [Ref. 40] for more details). In some cases, temperatures are measured after cessation of the fire transient.

The maximum average surface temperature of the inner shell at the cavity side are not presented here, but are listed in [Ref. 40]. These average surface temperatures are used to predict the cavity pressure under NCT and HAC, respectively.

Table 3.1-1 Summary of Maximum NCT Temperatures

[redacted]

Table 3.1-2 Summary of Maximum Hypothetical Fire Temperatures

[redacted]

3.1.4. Summary Tables of Maximum Pressures

The maximum internal pressures in the RT-200 are determined using the maximum temperatures presented in Table 3.1-1 and Table 3.1-2 above. Details of these pressure calculations are presented in Section 3.3.2 for NCT and in Section 3.4.3 for HAC. Table 3.1-3 presents a summary of the maximum pressure calculations for normal and accident conditions. These pressures are utilized in the structural evaluation presented for the cask body in Sections 2.6 and 2.7.

Table 3.1-3 Summary of Maximum Normal and Hypothetical Accident Condition Pressures

Conditions	Maximum Pressures	
	(gauge)	***(absolute)***
Normal Conditions of Transport	98.675 kPa	200 kPa
Hypothetical Accident Conditions	598.675 kPa	700 kPa

3.2. MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS

The material properties and specifications for the RT-200 materials of construction are presented in this section. They are carefully evaluated to ensure that for each thermal analysis:

- The appropriate thermal properties for the package materials are correctly incorporated into the thermal evaluations.
- Appropriate expressions are used for conductive, convective, and radiative heat transfer among package components, and from the surfaces of the package to the environment.

3.2.1. Material Properties

The thermal evaluation of the RT-200 is performed using material properties taken from standard industry references or manufacturer provided data in Table 3.5-1 through Table 3.5-4 in appendix 3.5.2. The thermal absorptivities and emissivities are appropriate for the package surface conditions and each thermal condition. When reporting a property as a single value, the evaluation shows that this value bounds the equivalent temperature-dependent property. This section includes references for the data provided.

Only room temperature values of conductivity, density, and specific heat are available for the foam (as summarized in [Ref. 37]). Quantitative temperature dependent material properties are not provided. However, most of the foam remains at temperatures close to ambient due to the dimensions of the RT-200 impact limiters which result in long heat conduction paths (see Figure 3.5-5 and Figure 3.5-6). Thus, reduction in the foam thermal properties due to elevated temperatures will not be significant. Therefore, the use of temperature-independent thermal properties is justified.

Information on the elastomeric O-ring material is provided in Appendix 4.6.3. The temperature range specified in Table 3.5-1 is conservative from the values specified in the appendix.

The air conductivity used to model air gaps is given in Table 3.5-5. For conservatism, this conductivity is sometimes multiplied by 10 in hypothetical accidental conditions (see § 3.1.1.2).
The thermal properties of the packaging materials are summarized in Table 3.5-1 to Table 3.5-4. For conservatism as explained in § 3.1.1.2 for the ceramic paper, the values of the thermal conductivity given in Table 3.5-4 are divided by a factor of 1.5 in normal condition of transport ["*(0) Shade*" and *"(1) Heat*"] and multiplied by a factor of 1.5 in accidental condition of transport [*"(4) Thermal"*].

3.2.2. Component Specifications

This section includes the technical specifications of the RT-200 components that are important to the thermal performance, as illustrated by the following examples:

- In the case of seals, the operation temperature limits
- Maximum allowable service temperatures for package components
- Minimum allowable service temperature of all components, which is less than or equal to -45°C.

Table 3.2-1 lists the maximum and/or minimum allowable temperatures for the critical cask components.

Table 3.2-1 Component Specifications – Minimum and maximum temperatures

Material	Min. temperature	Max. temperature	Reference
Stainless steels	-	>1,400°C *(melting T°)*	[Ref. 38]
Lead	-	327°C *(melting T°)*	[Ref. 37]
Foam	-	[redacted]	[Ref. 37]
O-rings	-45°C		Appendix **4.6.3**

3.3. Thermal Evaluation under Normal Conditions of Transport

This section describes the thermal evaluations performed for the RT-200 for the NCT specified in 10 CFR 71.71 [Ref. 36]. The evaluation considers the response of the RT-200 to a range of temperature and environmental conditions as described in Section 3.3.1.

3.3.1. Heat and Cold

This section demonstrates that the calculations for NCT do not result in a significant reduction in the RT-200 thermal effectiveness.

The component temperatures and pressures are compared to their allowable values and do not exceed them. This section explicitly shows that the package meets the requirement of a maximum temperature of the accessible package surface of 85°C (185°F) for exclusive use shipment when the package is subjected to the heat conditions of 10 CFR 71.43(g).

3.3.1.1. Load cases

Three load cases are analyzed in order to evaluate the RT-200 for the range of temperature and solar insolation conditions specified in 10 CFR 71.71 [Ref. 36] for normal conditions:

- “(0) Shade" as defined in 10 CFR 71.43 (g)
- “(1) Heat” as defined in 10 CFR 71.71 (c).
- “(2) Cold” as defined in 10 CFR 71.71 (c).

The "(2) Cold” case does not require further evaluation because the ambient temperature is -40°C and residual power and insolation are set to null, therefore the equilibrium temperature of the whole package is -40°C.

In the “(1) Heat” case, we consider:

- the maximum allowed residual power of the content: 1,200 W
- a stationary ambient temperature of 38°C and
- a constant insolation flux of 400 W/m², 12 hours per day (flux is null the rest of the day).

  Note: The chosen flux is penalizing since all the surfaces are:

  - either curved (10 CFR 71.71(c) specifies in this case a total insolation of 400 g cal/cm² for 12 hours per day, which corresponds to 388 W/m² for 12 hours per day)
  - or flat and vertical (the specified insolation for 12 hours is then 200 g cal/cm² which corresponds to a flux of 194 W/m² for 12 hours).

  The 400 W/m², 12 h/day is moreover in accordance with the IAEA Safety Standard [Ref. 43] for curved surfaces.

This case is used to define the maximum temperatures in normal conditions of transport. The results are taken as initial conditions of the “(4) Thermal” test of the hypothetical accident conditions of transport. It can also be used to define the maximum operating pressure.

The “(0) Shade" case is the same as the “(1) Heat” one but without insolation. This case is mainly used to compare the external temperature of the package to the limits specified in 10 CFR 71.43 (g).

3.3.1.2. Numerical model

The thermal evaluation of the RT-200 is performed using finite element modeling techniques, employing ANSYS finite element code [Ref. 39].

The outline shape of the cask is a sealed cylinder. A detailed 2D axisymmetric model of the cask including its major components has been modeled with ANSYS (more details on the analytical mode are given in [Ref. 40]). The major components are the inner shell, the outer shell, the lead shielding in between, the lid, the insulation of ceramic paper with its stainless-steel casing and the front and rear impact limiters, with their foam (Figure 3.5-1 to Figure 3.5-4 in appendix 3.5.3).

The following cases are simulated:

- "(0) Shade"
  A steady state calculation is used as there is no time dependent sunlight.
- *"(1) Heat"*
  A Transient analysis is used to model the day/night insolation cycle (12 hours at constant insolation power, and 12 hours without insolation). This cycle is repeated for 14.5 days until the maximum cask body temperature between two consecutive days is about constant. It stops at the end of a 12-hour insolation stage to be at the highest temperature of the day.

In all cases, the thermal exchanges simulated are:

- Conduction in all materials
- Convection from the outer surfaces to the ambient environment
- Radiation from the outer surfaces to the ambient environment
- Internal power of the content applied as a heat flow on the internal surfaces of the cask
- Insolation in the form of a 12 hour per day constant heat flux on the outer surfaces
- Conduction in air gaps
- Radiation through air gaps

3.3.1.3. Analysis results

The results of the steady state analysis of the cask model with impact limiters is shown in Figure 3.5-5 in appendix 3.5.3. [redacted]

For the transient analysis ("(1) Heat" case) the day/night insolation cycle (12 hours at constant insolation power, and 12 hours without insolation) is repeated 14.5 days until the maximum cask body temperature between two consecutive days is about constant. It stops at the end of a 12-hour insolation stage to be at the highest temperature of the day.

[redacted]

Figure 3.3-1 "(1) Heat" –temperatures history

[redacted]

3.3.2. Maximum Normal Operating Pressure

According to regulation provisions (10 CFR 71.4) the "Maximum normal operating pressure means the maximum gauge pressure that would develop in the containment system in a period of 1 year under the heat condition specified in § 71.71(c)(1), in the absence of venting, external cooling by an ancillary system, or operational controls during transport.")

To determine the maximum inner pressures, the temperature of the gas mixture within the cask is considered: the temperatures of the cask cavity under NCT are bounded by the upper temperature ranges that are assessed in section 3.3.1.3.

The maximum pressure results from the sum of three components:

- the pressure due to air in the cavity,
- the pressure due to water vapor in the cask, and
- the pressure due to the hydrogen and oxygen gases generated by radiolysis.

Detailed calculations, methods, assumptions and parameters are provided in [Ref. 41].

3.3.2.1. Calculation method

To determine the maximum normal operating pressure (MNOP), the temperature of the gas mixture within the cask is evaluated. The maximum temperature of the cask cavity under normal conditions is bounded by the upper temperature range of 80°C (see [Ref. 40]). The total pressure in the cavity is represented by the sum of the primary contributors to the pressure. This is the pressure due to the increased temperature of the cavity gas (ideal gas law), the pressure due to the presence of water vapor, and the pressure due to the generation of gas via radiolysis.

Per the ideal gas law, air pressure and water vapor pressure are directly proportional to the temperature and with increase in temperature, the total pressure also increases. Thus, the upper bound temperature will result in higher pressure levels for the cask compared to the lower bound.

The restriction of the contents to inorganic materials (metallic hardware) eliminates the potential for gas generation due to thermal degradation or biological activity. Thus, these gas sources are not considered in the evaluation.

The radiolytic generation of gases is limited to the radiolysis of the residual water. Hydrogen and oxygen may be produced in the cask by radiolytic decomposition of residual water in the cask contents. The cask loading must be limited to ensure that the amount of hydrogen generated in the cask cavity cannot be greater than 5% by volume of the contents that include water.

Hence, the cask atmosphere is assumed to contain 5% volume of hydrogen (H2) gas due to radiolysis of the water. To be conservative in the gas pressure calculations, the oxygen (O2) is assumed to be released into the cask atmosphere. By stoichiometry of the water molecule (H2O), the cask atmosphere will therefore also contain 2.5 vol. % oxygen (O2) gas generated by radiolysis (= ½ H2).

3.3.2.2. Pressure due to Initial Air in the Cavity

Per the ideal gas law, the increased partial pressure of the air (P_{air}) initially sealed in the fixed volume of the cask at the ambient temperature as it is heated is:

$$P_{air} = \frac{P_{init} \times T_{fin}}{T_{init}} = \frac{101.325\ kPa \times 353.15\ K}{294.25\ K} = 121.61\ kPa\ (abs.)$$

3.3.2.3. Pressure due to Vapor in the Cask

The cask cavity is assumed to contain a small amount of water. Thus, conservatively assuming a condensing surface temperature of +80°C, the water vapor pressure, P_{wv}, at this temperature is 47.39 kPa (according to [Ref. 41]).

$$P_{wv} = 47.39\ kPa\ (abs.)$$

3.3.2.4. Pressure due to Generation of Gas

According to the provisions stated in Section 3.3.2.1, and noting that partial pressures in an ideal gas mixture are additive and behave the same as ideal gas volume fraction or mole fractions, the partial pressure of hydrogen is described by the following equations:

$$P_{H2} = 0.05 \times (P_{air} + P_{wv} + P_{H2} + P_{O2})$$

$$P_{O2} = 0.5 \times P_{H2}$$

So:

$$P_{H2} = 0.05 \times (P_{air} + P_{wv} + 1.5P_{H2})$$

$$P_{H2} = \frac{0.05 \times (P_{air} + P_{wv})}{1 - 0.05 \times 1.5}$$

Solving the equations explicitly for P_{H2} gives:

$$P_{H2} = 9.14\ kPa\ (abs.)$$

3.3.2.5. NCT Total Pressure

Based on the stoichiometric relationship between hydrogen and oxygen liberated by radiolysis of water, and combining the pressure of the initially sealed air and water vapor, the total pressure in the cask at +80°C is:

$$P_{total} = P_{air} + P_{wv} + 1.5P_{H2} = 182.71\ kPa\ (abs.)$$

The maximum total pressure inside the cask cavity under NCT cannot exceed 183 kPa (absolute).

3.3.2.6. MNOP

According to previous results, the maximum pressure reached inside the cask cavity under NCT will not exceed 183 kPa (absolute), or 82 kPa (gauge).

➔ The MNOP value (as defined by 10 CFR 71.4) is thus conservatively set at 98.675 kPa or 200 kPa absolute for use in the cask analysis under NCT:

$$MNOP = 98.675\ kPa\ (gauge) = 200\ kPa\ (abs.)$$

3.4. THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT CONDITIONS

This section describes the thermal evaluation of the RT-200 under HAC. The RT-200 is evaluated by finite element computer analysis rather than physical testing to demonstrate the performance of the cask in response to the fire test conditions specified in 10 CFR 71.73(c) [Ref. 36]. The HAC defined in 10 CFR 71.73(c) are applied sequentially, considering the damaged condition of the packaging following the 9 m free drop and pin puncture accident events prior to the fire transient.

3.4.1. Initial Conditions

The "(4) Thermal" case takes the final temperatures of the "(1) Heat" case as initial temperatures. This case is simulated in two stages:

- a 30-minute transient analysis, "(4) Thermal - Fire", that simulates the fire conditions,
- followed by a 3 day post fire stage, "(4) Thermal – Post", to observe the temperature evolution after the fire.

The model used is based on the “(1) Heat” condition, with some modifications (removing parts of the impact limiters and of the body thermal protection, reduction of the air gaps). Those modifications are described below.

For accident conditions, drop test and pin puncture test will damage the impact limiters.

The FE model under HAC is identical to the model under NCT (see 3.3.1.2 and [Ref. 40]) except the damages due to HAC tests. To simulate these damages, some parts of the model have a “birth and death” behavior (Figure 3.5-7 in appendix 3.5.4). These parts are then deleted (put to death state) in the *“(4) Thermal”* case.

The geometry of the damaged impact limiter is arbitrarily diminished to a 30 mm stripe of foam. This largely covers the damage resulting from the 9 m regulatory free drop. A 1 m puncture drop may create a hole that reaches the inner stainless-steel shell of the impact limiter, but as the foam is intumescent, this hole will quickly be filled by char that will recreate the thermal protection.

The gaps between the impact limiters and the cask and between the lead and the outer shell are divided by 10. This is managed by multiplying the thermal conductance table of air in the contact elements by 10.

Other possible damage from the puncture test is damage to the side of the cask body. In this case, elements of the outer stainless-steel skin and the ceramic paper beneath the skin are removed from the damaged location. Because of the axial symmetry of the model, a circular band 150 mm wide has been removed (Figure 3.5-8 in appendix 3.5.4). This is a penalizing assumption since real damage will not occur across the whole circumference.

3.4.2. Fire Test Conditions

The HAC of transport is defined in [Ref. 36]: the study here considers only the *“(4) Thermal”* test defined in 10 CFR 71.73 (4). As clarified in §1.1 of [Ref. 42], the initial conditions are an ambient temperature of 38°C with the maximum insolation which corresponds to the *“(1) Heat”* case of the NCT defined in section 3.3.1.1.

After having reached the steady state of the *“(1) Heat”* case, the thermal test consists of modifying the ambient conditions (temperature of 800°C and no more insolation) for 30 minutes, and then returning to the initial conditions (ambient temperature of 38°C with insolation) for 7 days. During and after the test, the emissivity/absorptivity of the external surfaces are modified to be 0.8 (as specified in 10 CFR 71.73 (4) [Ref. 36]). During the 30 minutes of fire conditions, the convection coefficient of the external surfaces used is increased to 10 W/m²/°C which corresponds to a typical forced convection coefficient (*value advised in §728.30. of [Ref. 44]*).

No artificial cooling has been considered.

3.4.3. Maximum Temperatures and Pressure

This section summarizes the peak accident condition temperatures of RT-200 components as a function of time both during and after the fire, as well as the maximum temperatures from the post-fire, steady-state condition. This section includes those temperatures at locations in the package that are significant to the safety analysis and review. The calculations of transient temperatures trace the temperature-time history up to and past the time at which maximum temperatures are achieved and begin to fall. The calculations confirm that these temperatures do not exceed their maximum allowable values. It also confirms that the lead shielding does not reach melting temperature.

The RT-200 is evaluated structurally for the maximum HAC temperatures and pressures in Chapter 2, Section 2.7.4 (Thermal).

3.4.3.1. Maximum Temperatures

The results from the RT-200 HAC fire transient analyses for the side and top pin puncture accident model are summarized in this section. Additional details regarding the analytical results are available in [Ref. 40].

The results of the HAC fire test (*"(4) Thermal"* case) are shown in Figure 3.4-1 (and Figure 3.5-9 and Figure 3.5-10 in appendix 3.5.4).

[redacted]

[redacted]

[redacted]

[redacted]

Figure 3.4-1 "(4) Thermal - Post" – temperature history

[redacted]

3.4.3.2. Maximum Accident Condition Pressure

The evaluation of the maximum pressure within the RT-200 considers fire-induced increases in package temperatures. The value of this maximum pressure is consistent with the values used in the Structural Evaluation and Containment sections.

Similar to the calculation of the maximum normal operating pressure in Section 3.3.2, the maximum accident condition pressure is calculated using bounding assumptions for the temperatures in the cask as a result of the HAC fire transient. The maximum pressure is the sum of four components:

- the pressure due to the initially sealed air in the cavity,
- the pressure due to water vapor in the cask,
- the pressure due to the hydrogen gases generated by radiolysis, and
- the pressure due to the oxygen gases generated by radiolysis.

Detailed calculations, methods, assumptions, and parameters are provided in [Ref. 41].

3.4.3.2.1. <u>Calculation Method</u>

To determine the maximum pressure in the RT-200, the temperature of gas mixture within the cask is evaluated. [redacted]

[redacted] The total pressure in the cavity is then represented by the sum of the primary contributors to the pressure (according to the method described in Section 3.3.2.1 for the NCT evaluation).

3.4.3.2.2. Pressure due to Initial Air in the Cavity

Per the ideal gas law, the increased partial pressure of the air (P_{air}) initially sealed in the fixed volume of the cask at the ambient temperature as it is heated is:

$$P_{air} = \frac{P_{init} \times T_{fin}}{T_{init}} = \frac{101.325\ kPa \times 423.15\ K}{294.25\ K} = 145.8\ kPa\ (abs.)$$

3.4.3.2.3. Pressure due to Vapor in the Cask

The cask cavity is assumed to contain a small amount of water. Thus, conservatively assuming a condensing surface temperature of 150°C [redacted] the water vapor pressure, P_{wv}, at this temperature is then 475.8 kPa (according to [Ref. 41]).

$$P_{wv} = 475.8\ kPa\ (abs.)$$

3.4.3.2.4. Pressure due to Generation of Gas

According to 0 and 3.4.3.2.1 provisions and noting that partial pressures in an ideal gas mixture are additive and behave the same as ideal gas volume fraction or mole fractions, the partial pressure of hydrogen is described by the following equations:

$$P_{H2} = 0.05 \times (P_{air} + P_{wv} + P_{H2} + P_{O2})$$
$$P_{O2} = 0.5\ \times P_{H2}$$

So:

$$P_{H2} = 0.05 \times (P_{air} + P_{wv} + 1.5P_{H2})$$
$$P_{H2} = \frac{0.05\ \times (P_{air} + P_{wv})}{1 - 0.05 \times 1.5}$$

Solving the equations explicitly for P_{H2} gives:

$$P_{H2} = 33.6\ kPa\ (abs.)$$

3.4.3.2.5. HAC Total Pressure

Based on the stoichiometric relationship between hydrogen and oxygen liberated by radiolysis of water, and again combining the pressure of the initially sealed air and water vapor, the total pressure in the cask at +150°C is:

$$P_{total} = P_{air} + P_{wv} + 1.5P_{H2} = 672.0\ kPa\ (abs.)$$

The maximum total pressure inside the cask cavity will not exceed 672 kPa under HAC.

For subsequent analysis of the cask under HAC, it can be conservatively recommended to consider the following bounding values for the maximum inner pressure:

700 kPa (abs.) or 598.675 kPa (gauge)

3.4.4. Maximum Thermal Stresses

The RT-200 cask is evaluated for the stresses produced by the temperature gradients in the cask body that result from exposure of the cask to the HAC fire transient. This evaluation, which utilizes the temperature distributions resulting from the fire accident as described in Section 3.4.3, is presented in detail in Chapter 2, Section 2.7.4 (Thermal).

3.4.5. Accident Conditions for Fissile Material Packages for Air Transport

This Section is not applicable. The RT-200 is not intended to be used for fissile material air transport.

3.5. Appendix

This appendix contains proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390. This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

3.5.1. List of References

This section provides a list of the documents that are referred to within section 3 – “Thermal Evaluation”. A comprehensive summary list of the entire SAR references is provided in Section 0 – “Introduction”.

Some of the references listed below might contain proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390: when it is the case, the reference is then clearly identified "(PROPRIETARY)". This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

Ref. 35 Robatel Technologies, LLC, Quality Assurance Program Description 10 CFR 71 Subpart H for Packaging and Transportation of Radioactive Material, Rev. 4, Dated August 11, 2021, and NRC Approved on March 21, 2012 (PROPRIETARY)

Ref. 36 U.S. Nuclear Regulatory Commission, 10 CFR Part 71 – Packaging and Transportation of Radioactive Material

Ref. 37 Robatel Industries, “RT-200 – Material Thermal Properties”, Technical note, RT-200 NTE 3001, Rev. C (PROPRIETARY)

Ref. 38 Sanghavi Bothra Engineering Co. Pvt. Ltd. (SBE), “304/304L Stainless-steel Product Mechanical and Physical Properties”

Ref. 39 ANSYS, Release 21.2, ANSYS Inc., Canonsburg, PA, October 2011

Ref. 40 Robatel Industries, “RT-200 – Thermal Calculation”, Technical note, RT-200 NTE 3002, Rev. C (PROPRIETARY)

Ref. 41 Robatel Industries, “RT-200 – Pressures Calculations”, Technical note, RT-200 NTE 3003, Rev. C (PROPRIETARY)

Ref. 42 U.S. Nuclear Regulatory Commission, Regulatory Guide 7.8, “Load combinations for the structural analysis of shipping casks for radioactive material”, March 1989

Ref. 43 IAEA Safety standards, Specific Safety Requirements, “Regulations for the Safe Transport of Radioactive Material (2018 Edition)”, SSR-6 (Rev. 1)

Ref. 44 IAEA Safety standards, Specific Safety Guide, “Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2018 Edition)”, SSG-26 (Rev. 1)

3.5.2. Material Thermal Properties Tables

This appendix collects the summary tables of the main thermal properties of materials. Values mainly come from [Ref. 37].

Table 3.5-1 Temperature-Independent Material Properties

[redacted]

Note [(1)]: Only small parts that locally cover the trunnions are made of this foam. For thermal analysis, they are not specifically modeled. As discussed hereafter, such local singularities don't significantly drive the overall thermal behavior of the cask.

Table 3.5-2 Temperature-Dependent Material Properties - Stainless-steel

[redacted]

Note: the values corresponding to the 304L type are used for all metallic parts

Table 3.5-3 Temperature-Dependent Material Properties - Lead

[redacted]

Table 3.5-4 Temperature-Dependent Material Properties - Ceramic paper

[redacted]

Note: the values of the conductivity of this table are divided or multiplied by a factor 1.5 in the model respectively in NCT and HAC for penalizing considerations.

Table 3.5-5 Temperature-Dependent Material Properties - Air

[redacted]

Note 1: data from [Ref. 40]

Note 2: the specific heat and density are not used in the model as the air mass and thermal capacity are negligible in comparison with the materials of the cask.

3.5.3. NCT FE Analysis Illustrations

Illustrations of this appendix come from [Ref. 40].

3.5.3.1. NCT FE Model Illustrations

Figure 3.5-1 Global views of the model (unmeshed and meshed)

[redacted]

Figure 3.5-2 Model detailed views of the ends

[redacted]

Figure 3.5-3 Mesh detailed views

[redacted]

Figure 3.5-4 Contacts for Gaps modeling

[redacted]

3.5.3.2. NCT FE Results Illustrations

Figure 3.5-5 "(0) Shadow" – stationary temperature

[redacted]

Figure 3.5-6 "(1) Heat" – maximum temperature over time

[redacted]

3.5.4. HAC FE Analysis Illustrations

Illustrations of this appendix come from [Ref. 40].

3.5.4.1. HAC FE Model Illustrations

Figure 3.5-7 Model detailed views – Birth and Death elements for "(4) Thermal" case

[redacted]

Figure 3.5-8 Model detailed views - "(4) Thermal" case

[redacted]

3.5.4.2. HAC FE Results Illustrations

Figure 3.5-9 "(4) Thermal - Fire" – maximum temperature over time

[redacted]

Figure 3.5-10 "(4) Thermal - Post" – maximum temperature over time

[redacted]

4. CONTAINMENT

This chapter demonstrates the RT-200 containment boundary compliance with the permitted activity release limits specified in 10 CFR 71.51(a)(1) and 10 CFR 71.51(a)(2) [Ref. 45] for both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) of transport.

Due to the variety of inventories, diversity in both isotopic composition and in total activity concentration, the RT-200 has been established as a leak tight container. Leak tight is a degree of package containment that, in a practical sense, precludes any significant release of radioactive materials. This degree of containment is achieved by demonstration of a leakage rate less than or equal to $1 \cdot 10^{-7}$ ref-cm^3/s of air at an upstream pressure of 1 atmosphere absolute and a downstream pressure of 0.01 atmospheres absolute or less (ANSI N14.5 [Ref. 46]).

The containment review is based in part on the descriptions and evaluations presented in the General Information, Structural Evaluation and Thermal Evaluation sections of the application. Similarly, results of the containment review are considered in the review of Package Operations and Acceptance Tests and Maintenance Program.

Table of Content

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4.1. Description of the Containment System

This section provides a detailed description of the containment system. This description includes the containment vessel, welds, seals, lid, cover plates, and closure devices relevant to the containment boundary of the cask.

4.1.1. Containment System

The package containment system is defined as the containment vessel (the inner shell, the rear forging plate and the front forging flange), together with the associated lid, O-ring seals, and lid closure bolts. The containment cavity consists of a wide cylinder (see main dimensions in table 1.3-2 in appendix of SAR Section 1.3).

The containment vessel is fabricated in stainless-steel. [redacted]

The lid is attached to the cask body with thirty (30) M42 round head hex bolts.

The inner shell is shown to maintain stresses within allowable limits in Chapter 2, Section 2.6 for NCT and Section 2.7 for HAC. These evaluations demonstrate that the inner shell maintains its integrity and provides containment along with the closure system as described in Section 4.1.4.

4.1.2. Containment Penetration

There are three locations where the containment vessel may be penetrated (overview provided by Figure 1.2-1). For each location, an inner O-ring seals the containment boundary:

- Lid,
- Cask vent port cover plate,
- Cask drain port cover plate.

A vent port and a drain port penetrate the containment vessel into the main cask cavity. They both contain a quick disconnect valve and are sealed with a cover plate. The lid and the cover plates are sealed with elastomer O-rings. Figure 4.6-1 in Appendix 4.6.2 illustrates the containment system and the containment boundaries. The quick disconnect valves are not part of the containment boundaries.

The RT-200 does not rely on any valve or pressure relief device to meet the containment requirements. The quick disconnect valves are protected by the cover plates which protect the valve from unauthorized operation and provide a sealed enclosure to retain any leakage from the device.

4.1.3. Welds and Seals

[redacted]

[redacted]

[redacted]

The following seals form part of the containment boundary:

- The inner elastomer O-ring on the lid
- The inner elastomer O-ring on the vent port cover
- The inner elastomer O-ring on the drain port cover

O-rings may be supplied by manufacturers such as those in the Parker O-Ring Handbook [Ref. 51], Trelleborg Sealing Solutions O-Ring and Backup Rings Catalog [Ref. 52] or James Walker 'O' Ring Guide [Ref. 53]. Additional information on the O-rings taken from these references is provided in Appendices 4.6.3 and 4.6.4.

These references contain information regarding the operating temperature range, gap permeability, and compression set for the materials. The temperature performance of the O-rings is summarized in Table 4.6.3-1 (in Section 4.6.3 Appendix) which is used as input data in Chapter 3 thermal evaluation (see Table 3.2-1 of Section 3.2). The capability of the O-rings to provide positive sealing of the closure lid and cover plates is addressed in Chapter 2.

Elastomer radiation resistance is addressed in "Radiation Resistance of Elastomers" [Ref. 50] indicating that the material is radiation resistant up to $5 \cdot 10^8$ rads while retaining reasonable flexibility and strength, hardness, and very good compression set resistance (see Appendix 4.6.5).

The package and the contents do not include materials that may cause any significant chemical, galvanic, or other reactions (see section 2.2.2, 1.2.2.1.10 and 1.2.2.2.10). Therefore, no such reactions will occur between EPDM O-rings and the content or the package.

4.1.4. Closure

The closure lid consists of a partially recessed thick stainless-steel plate (main thickness in Table 1.3-3 in Appendix 1.3.2 of Chapter 1). The lid is supported at the perimeter of the cylindrical body by a thick flange (front forging) [redacted]

The lid is attached to the cask body by thirty (30) M42 round head hex bolts. Two (2) concentric elastomer O-rings are retained in machined grooves at the lid perimeter. Groove dimensions prevent over-compression of the O-rings by the closure bolt preload forces and hypothetical accident impact forces.

The two (2) quick-disconnect valves are housed under a stainless-steel cover plate. The two quick-disconnect valve cover plates are attached to the cask body with six (6) equally spaced M16 round head hex bolts. Two (2) concentric elastomer O-rings are retained in machined grooves at the cover plate perimeter.

The torque requirements for the lid and cover plate bolts are listed in Table 1.3-5 in Appendix 1.3.8.

Due to this closure setup, continuous venting from the RT-200 is precluded.

As stated above, multiple bolted closures seal the containment system. These closures contain numerous bolts that are required to be tightened to specified torques using approved procedures during the cask loading process. Secure closure is assured by the torque values specified and the assembly verification leak test performed prior to transport. The specified torques are calculated to ensure that sufficient preload is applied to the bolts to resist loads arising from normal and accident conditions.

The closure system is evaluated for NCT and HAC in Chapter 2. Closure bolts are shown to maintain adequate design margin and allow the O-rings to always maintain a positive seal.

4.1.5. Cavity Volume, Conditions, and Contents

Relying on the cavity dimensions provided in Table 1.3-2 in Appendix 1.3.2, the volume of the cask cylindrical cavity (see Table 4.6.2-1 in Appendix 4.6.2) is:

$$V_{cavity} = 4.34 \cdot 10^6\ cm^3$$

Conservatively, this volume does not consider small volumes of the containment cavity such as the central hole of the lid which accommodates the disposable insert lifting lug, or, the vent and drain port respectively at the top and at the bottom of the inner cavity (see Figure 4.6-1).

The air temperatures within the cask under normal and accident conditions are determined based on the maximum average internal cavity temperatures for NCT and HAC. Resulting bounding pressures and temperatures are summarized in Table 4.2.1-1. They come from evaluations detailed in the technical note RT-200 NTE 3003 [Ref. 49].

The standard leakage rate is the leakage rate of dry air when it is leaking from 1 atm (upstream pressure) to 0.01 atm (downstream pressure) at 298 K (ANSI N14.5 [Ref. 46]).

Dynamic viscosity values were generated based on the Sutherland equation (cf. "Viscous fluid flow" [Ref. 47]):

$$\mu_{gas}\ (T) = \mu_{gas}(T_{ref})\ \left(\frac{T}{T_{ref}}\right)^{\frac{3}{2}} * \frac{T_{ref} + S}{T + S}$$

where:

- $\mu_{gas}(T)$ is the dynamic viscosity of gas at a given temperature in cP (centiPoise)
- $\mu_{gas}(T_{ref})$ is the dynamic viscosity of gas at a reference temperature T_{ref} in cP:
  - $\mu_{air}(273\ K) = 0.01716$ cP

  - μ_{He}(273 K) = 0.0187 cP
- T is the temperature in Kelvin at which the viscosity is calculated
- S is the Sutherland's constant:
  - S = 111 K for dry air at normal atmospheric pressure
  - S = 79.4 K for helium at normal atmospheric pressure.

Table 4.2.1-1 summarizes the main parameters for NCT and HAC containment evaluations.

4.2. CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT

The RT-200 package is designed, constructed, and prepared for shipment so that, under the conditions specified in 10 CFR 71.71 [Ref. 45], the package meets the containment requirements of 10 CFR 71.51 (a) (1).

4.2.1. NCT Pressurization of the Containment Vessel

According to section 3.3.2, the package Maximum Normal Operating Pressure (MNOP) is 98.675 kPa gauge (= 200 kPa abs.).

Table 4.2.1-1 Containment parameters for NCT and HAC

Parameter	Normal Conditions	Accident Conditions	Standard Conditions
P_u [atm] abs. *(upstream pressure)*	1.99	6.91	1
P_d [atm] abs. *(downstream pressure)*	1	1	0.01
P_a [atm] abs. *(average pressure)*	1.49	3.95	0.505
T [K] *(gas temperature)*	353.15 K (80°C)	423.15 K (150°C)	298 K (25°C)
M [g/mol] *(molar weight)*	29 (air) 4 (He)	29 (air) 4 (He)	29 (air) 4 (He)
μ [cP] *(dynamic viscosity)*	0.0209 (air) 0.0224 (He)	0.0238 (air) 0.0253 (He)	0.0184 (air) 0.0199 (He)

4.2.2. NCT Containment Criterion

The package is designed to the “leaktight” containment criterion per ANSI N14.5 [Ref. 46], therefore the leakage rate criterion is 10^{-7} ref-cm^3/s.

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 that the containment boundary, seal region, and closure bolts do not undergo any inelastic deformation when subjected to the conditions specified in 10 CFR 71.71. The maximum calculated NCT temperatures summarized in Section 3.3 show that the seals, bolts and containment system materials of construction do not exceed their allowable temperature limits when subjected to the conditions specified in 10 CFR 71.71. Thus, there is no modification of the tightness of the package and then no loss of radioactive material since the package stays "leaktight" (10^{-7} ref-cm^3/s).

4.3. CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS

The RT-200 package is designed, constructed, and prepared for shipment so that, under the conditions specified in 10 CFR 71.73 [Ref. 45], the package meets the containment requirements of 10 CFR 71.51 (a) (2).

4.3.1. HAC Pressurization of the Containment Vessel

According to section 3.4.3.2, the maximum internal pressure of the RT-200 package under HAC is 700 kPa (abs.).

4.3.2. HAC Containment Criterion

The package is designed to the "leaktight" containment criterion per ANSI N14.5 [Ref. 2], therefore the leakage rate criterion is 10^{-7} ref-cm^3/s.

4.3.3. Compliance with HAC Containment Criterion

Compliance with the HAC containment criterion is demonstrated by analysis. The structural evaluation presented in Section 2.7 shows that there would be no loss or dispersal of radioactive contents, and that the structural integrity of the containment boundary, seal region, and closure bolts is preserved when subjected to the conditions of 10 CFR 71.73. The maximum calculated HAC temperatures summarized in Section 3.4.3 show that the seals, bolts, and containment system materials of construction do not exceed their allowable temperature limits when subjected to the conditions of 10 CFR 71.73. Thus, there is no modification of the tightness of the package and then no loss of radioactive material since the package stays "leaktight" (10^{-7} ref-cm^3/s).

4.4. LEAKAGE RATE TESTS FOR TYPE B PACKAGES

This section describes the leakage tests used to show that the RT-200 meets the containment requirements of 10 CFR 71.51 [Ref. 45]. Leak test requirements are further specified in Chapter 7 and Chapter 8.

The following leakage tests are conducted on the RT-200 as required by ANSI N14.5 [Ref. 46]:

Table 4.4-1 Leakage tests of the RT-200 Package

Test	Frequency	Test Gas	Acceptance Criteria
Fabrication	Prior to the first use of the RT-200	Helium	≤ L_{He}*
Maintenance	Prior to returning the cask to service after maintenance, repair or replacement of components of the containment system		
Periodic	Annually		
Pre-Shipment	Before each shipment, after the contents are loaded and the package is closed	Air	≤ L_{P_u}*, or No leakage at a sensitivity ≤ 10^{-3} ref-cm^3/sec

* Adjusted for the individual properties of the test gases (see example below). Fabrication, Maintenance and Periodic leakage tests may be performed using helium as the test gas. The acceptance criterion for these tests is the equivalent reference leakage rate for helium gas, L_{He} (example of calculation in Section 4.4.2). Pre-Shipment leakage tests may be performed using air as the test gas. The acceptance criterion for these tests is the equivalent reference leakage rate for air, L_{P_u} (example of calculation in Section 4.4.3).

4.4.1. Allowable Leakage Rates at Test Conditions

Un-choked flow correlations are used as they better approximate the true measured flow rate for the leakage rates associated with transportation packages. Using the equations for molecular and continuum flow provided in NUREG/CR-6487 [Ref. 48], the corresponding capillary diameter (or leak hole diameter) is calculated for the RT-200 for standard test conditions by solving Equation 4.1 for D, the capillary diameter. The capillary length required for Equation 4.1 for the containment system is conservatively chosen as the O-ring groove width in the vent or drain port cover plate lid, which is 0.49 cm. This capillary length bounds the cask lid and is therefore applicable to the cask lid as well.

Equation 4.1

$$L_{P_a} = \left(\frac{2.49 \cdot 10^6\, D^4}{a \cdot \mu} + \frac{3.81 \cdot 10^3 D^3 \sqrt{\frac{T}{M}}}{a \cdot P_a} \right) \cdot (P_u - P_d)$$

where:

L_{Pa} is the allowable leakage rate at the average pressure for standard conditions [cm^3/s],

a is the capillary length [0.49 cm],

T is the temperature for standard conditions [298 K],

M is the gas molecular weight [g/mol],

μ is the gas dynamic viscosity [cP],

P_u is the upstream pressure [atm],

P_d is the downstream pressure [atm],

P_a is the average pressure; $P_a = (P_u + P_d)/2$ for standard conditions [atm], and

D is the capillary diameter [cm].

The capillary diameter is determined using the parameters for standard conditions presented in Table 4.2.1-1.

The allowable leakage rate for leaktight conditions is at the upstream pressure. The ratio presented in Equation 4.2 is used to convert Equation 4.1 to upstream leakage rate so that the capillary diameter can be determined.

Equation 4.2

$$L_{P_u} = L_{P_a} \frac{P_a}{P_u}$$

$$L_{P_u} = \left(\frac{2.49 \cdot 10^6 \ \mathrm{D}^4}{\mathrm{a} \cdot \mu} + \frac{3.81 \cdot 10^3 \mathrm{D}^3 \sqrt{\frac{\mathrm{T}}{\mathrm{M}}}}{\mathrm{a} \cdot \mathrm{P_a}} \right) \cdot (\mathrm{P_u} - \mathrm{P_d}) \cdot \frac{P_a}{P_u}$$

where:

L_{Pa} is the allowable leakage rate at the average pressure for standard conditions [cm^3/s],

L_{Pu} is the allowable leakage rate at the upstream pressure for standard conditions [cm^3/s],

P_u is the upstream pressure [atm],

P_d is the downstream pressure [atm], and

P_a is the average pressure; $P_a = (P_u + P_d)/2$ [atm].

The minimum required sensitivity for the leakage test procedures is established by ANSI N14.5 Section 8.4 [Ref. 46] as shown in Equation 4.3.

Equation 4.3

S ≤ ½ Leakage Rate[1]

Leakage rate in this case is the upstream pressure leakage rate at standard conditions.

[1]The pre-shipment leakage rate test need not be more sensitive than $1 \cdot 10^{-3}$ ref-cm^3/s.

4.4.2. Determination of Equivalent Reference Leakage Rate for Helium Gas

This section determines the allowable leakage rate using helium gas which may be used to perform the annual verification leakage tests summarized in Table 4.4-1. This calculation uses formulas provided by ANSI N14.5 [Ref. 46].

The reference air leakage rate is $1.00 \cdot 10^{-7}$ ref-cm^3/s based on leaktight criterion [Ref. 46].

Using Equation 4.2, the maximum capillary diameter, D_{max}, was determined, using standard conditions:

$$L_{P_u} = \left(\frac{2.49 \cdot 10^6\ D^4}{0.49 \cdot 0.0184} + \frac{3.81 \cdot 10^3 D^3 \sqrt{\frac{298}{29}}}{0.49 \cdot 0.505} \right) \cdot (1 - 0.01) \cdot \frac{0.505}{1} = 1 \cdot 10^{-7}\ cm^3/s$$

Diameter values are inputted until the result of the above calculation is roughly equivalent to $1 \cdot 10^{-7}$ ref-cm^3/s (using the Newton-Raphson method, for example). Solving for D_{max} iteratively yields:

$D_{max} = 1.3235 \cdot 10^{-4}$ cm

The equivalent air/helium mixture that would leak from D_{max} during a leak test, as described in Table 4.2.1-1, is determined.

The leakage tests may be performed with an air/helium mixture, for example.

$P_{mix} = P_u = P_{He} + P_{air}$

$P_a = 0.5 \cdot (P_{mix} + P_d)$

The mass of the mixture of air/helium gases is then determined:

$M_{mix} = \frac{M_{He}P_{He} + M_{air}P_{air}}{P_{mix}}$ → Eqn. (B.7) from ANSI N14.5 [Ref. 46]

$\mu_{mix} = \frac{\mu_{He}P_{He} + \mu_{air}P_{air}}{P_{mix}}$ → Eqn. (B.8) from ANSI N14.5 [Ref. 46]

Note: Change in viscosity as a function of temperature must be taken into consideration.

Determine L_{mix} as a function of temperature.

$F_c(D_{max}) = \frac{2.49 \cdot 10^6 \cdot (D_{max})^4}{a \cdot \mu_{mix}}$ Equation (B.3) from ANSI N14.5 [Ref. 46]

$F_m(T) = \frac{3.81 \cdot 10^3 \cdot (D_{max})^3 \sqrt{\frac{T}{M_{mix}}}}{a \cdot P_a}$ Equation (B.4) from ANSI N14.5 [Ref. 46]

$L_{mix}(T) = (F_c + F_m(T))\ (P_{mix} - P_d)\ \frac{P_a}{P_{mix}}$ Equation (B.5) from ANSI N14.5 [Ref. 46]

The helium component of this leak rate is determined by multiplying the leak rate of the mixture by the ratio of the helium partial pressure to the total mix pressure.

$$L_{He}(T) = L_{mix}(T) \cdot \frac{P_{He}}{P_{mix}}$$

If the measured leakage rate is below L_{He}, then the leaktight criterion has been met.

Example of application:

Determination of the equivalent reference leakage rate for helium gas with P_{He} = 0.7 atm and for standard conditions as described in Table 4.2.1-1.

The capillary diameter is $D_{max} = 1.3235 \cdot 10^{-4}$ cm according to Section 4.4.2.

The leakage tests are performed with an air/helium mixture.

$P_{mix} = P_{He} + P_{air} = 1$ atm

$P_{he} = 0.7$ atm

$P_{air} = 0.3$ atm

$P_a = 0.5 \cdot (P_{mix} + P_d) = 0.505$ atm

The mass of the mixture of air/helium gases is then determined at room temperature:

$$\mathrm{M_{mix}} = \frac{\mathrm{M_{He}P_{He} + M_{air}P_{air}}}{\mathrm{P_{mix}}} = \frac{4*0.7+29*0.3}{1} = 11.5\ g/mol$$

$$\mu_{\mathrm{mix}} = \frac{\mu_{\mathrm{He}}\mathrm{P_{He}} + \mu_{\mathrm{air}}\mathrm{P_{air}}}{\mathrm{P_{mix}}} = \frac{0.0199*0.7+0.0184*0.3}{1} = 0.01945\ cP$$

Determine L_{mix} as a function of temperature:

$$F_c(D_{max}) = \frac{2.49 \cdot 10^6 \cdot (\mathrm{D_{max}})^4}{\mathrm{a} \cdot \mu_{\mathrm{mix}}} = \frac{2.49 \cdot 10^6 \cdot (1.3235 \cdot 10^{-4})^4}{0.49*0.01945} = 8.02 \cdot 10^{-8}\ \mathrm{cm^3/s}$$

$$F_m(T) = \frac{3.81 \cdot 10^3 \cdot (\mathrm{D_{max}})^3 \sqrt{\frac{\mathrm{T}}{\mathrm{M_{mix}}}}}{\mathrm{a} \cdot \mathrm{P_a}} = \frac{3.81 \cdot 10^3 \cdot (1.3235 \cdot 10^{-4})^3 \sqrt{\frac{298}{11.5}}}{0.49*0.505} = 1.82 \cdot 10^{-7}\ \mathrm{cm^3/s}$$

$$L_{mix}(T) = (F_c + F_m(T))\ (P_{mix} - P_d)\ \frac{P_a}{P_{mix}} = (8.02 \cdot 10^{-8} + 1.82 \cdot 10^{-7}) \cdot (1 - 0.01) \cdot 0.505/1$$

$$L_{mix}(T) = 1.31 \cdot 10^{-7}\ \text{ref-cm}^3/\text{s}$$

The helium component of this leak rate is determined by multiplying the leak rate of the mixture by the ratio of the helium partial pressure to the total mix pressure.

$$L_{He}(T) = L_{mix}(T) \cdot \frac{P_{He}}{P_{mix}} = 1.31 \cdot 10^{-7} \cdot \frac{0.7}{1}$$

$$L_{He}(T) = 9.16 \cdot 10^{-8} \text{ ref-cm}^3\text{/s}$$

In this case, in standard conditions and with P_{He} = 0.7 atm, the leaktight criterion is met if the measured leak rate is ≤ $9.16 \cdot 10^{-8}$ ref-cm^3/s.

4.4.3. Determination of Equivalent Reference Leakage Rate for Air

For the pre-shipment leakage test described in Table 4.4-1, the acceptance criterion is based on standard leakage test conditions. NUREG/CR-6487 Section 2.2.6 [Ref. 48] defines the standard leak rate as corresponding to the upstream volumetric flow rate of dry air with an upstream pressure of 1 atmosphere, a downstream pressure of 0.01 atmosphere, and a temperature of 298 K.

Tests may be performed under other conditions, provided the acceptance criterion at the testing conditions corresponds to the calculated standard leakage rate acceptance criterion. The method for determining the corresponding leak rate is described in ANSI N14.5 Section B.4.4 [Ref. 46] (see example below).

Any gas leakage can be stated in terms of the reference conditions by using the appropriate conversion. The conversion is made by calculating the capillary diameter for a given leakage and set of conditions using Equation 4.1 and Equation 4.2.

Then, this capillary diameter, and the reference conditions of leakage are used to calculate the corresponding reference leakage rate (Equation (B.5) from ANSI N14.5 [Ref. 46]).

In every case, the acceptance criterion for pre-shipment leakage rate testing shall be either:

- a leakage rate of not more than the reference air leakage rate, or
- no detected leakage when tested to a sensitivity of at least 10^{-3} ref-cm^3/s.

<u>Example of application:</u>

Determination of equivalent reference leakage rate for air with P_u = 3 atm, P_d = 1 atm and T = 373 K.

Using Equation 4.2, the maximum capillary diameter, D_{max}, is determined, using standard conditions:

$$L_{P_u} = \left(\frac{2.49 \cdot 10^6\ D^4}{0.49 \cdot 0.0184} + \frac{3.81 \cdot 10^3 D^3 \sqrt{\frac{298}{29}}}{0.49 \cdot 0.505} \right) \cdot (1 - 0.01) \cdot \frac{0.505}{1} = 1 \cdot 10^{-3}\ cm^3/s$$

using Newton-Raphson method:

$D_{max} = 1.5939 \cdot 10^{-3}$ cm

The leakage tests are performed with air:

P_u = 3 atm

P_d = 1 atm

$P_a = 0.5 \cdot (P_u + P_d)$ = 2 atm

Using Sutherland equation to determine the dynamic viscosity of air at 373 K (see Section 4.1.5):

$$\mu_{air}\ (373\ \mathrm{K}) = \mu_{air}(273.15\ K) \left(\frac{373}{273.15}\right)^{\frac{3}{2}} * \frac{273.15 + 111}{373 + 111}$$

$$\mu_{air}\ (373\ \mathrm{K}) = 0.0217\ \mathrm{cP}$$

Determine L_{mix} as a function of temperature:

$$F_c(D_{max}) = \frac{2.49 \cdot 10^6 \cdot (D_{max})^4}{a \cdot \mu_{air}} = \frac{2.49 \cdot 10^6 \cdot (1.5939 \cdot 10^{-3})^4}{0.49 * 0.0217} = 1.51 \cdot 10^{-3}\ \mathrm{cm^3/s}$$

$$F_m(T) = \frac{3.81 \cdot 10^3 \cdot (D_{max})^3 \sqrt{\frac{T}{M_{air}}}}{a \cdot P_a} = \frac{3.81 \cdot 10^3 \cdot (1.5939 \cdot 10^{-3})^3 \sqrt{\frac{373}{29}}}{0.49 * 2} = 5.65 \cdot 10^{-5}\ \mathrm{cm^3/s}$$

$$L_{Pu}(T) = (F_c + F_m(T))\ (P_u - P_d)\ \frac{P_a}{P_u} = (1.51 \cdot 10^{-3} + 5.65 \cdot 10^{-5}) \cdot (3 - 1) \cdot 2/3$$

$L_{Pu}(T) = 2.09 \cdot 10^{-3}$ ref-cm^3/s

In this case, with P_u = 3 atm, P_d = 1 atm and T = 373 K, the pre-shipment criterion is met if the measured leak rate is ≤ $2.09 \cdot 10^{-3}$ ref-cm^3/s.

4.5. HYDROGEN GAS GENERATION

Hydrogen gas buildup in loads containing waste material typically occurs due to radiolysis of hydrogenous material in the contents. As hydrogen is generated, it could potentially accumulate within the cask cavity in flammable concentrations. Based on NRC guidance, the flammability limit of 0.05 volume fraction (mole fraction and volume fraction is interchangeable when discussing ideal gas buildup) hydrogen in air was measured in accordance with NUREG/CR-6673 “Hydrogen Generation in TRU Waste Transportation Packages” [Ref. 54].

The analysis concerns the gas generation of residual water in the containment vessel as the exclusive source of hydrogen in the cask's cavity. Therefore, if the content loaded inside the cavity is dry, no hydrogen gas will be generated.

The rate of gas generation by radiolysis in water is dependent upon the type of incident radiation. Alpha emitters generate more hydrogen per unit of energy deposited than gamma/beta emitters. Since NUREG/CR-6673 [Ref. 54] is primarily focused on the alpha radiation predominant in TRU waste, “EPRI NP-5977” [Ref. 55] and “RH-TRU Payload Appendices” [Ref. 56] are utilized to obtain beta and gamma radiation G values for water.

An application example of hydrogen gas generation analysis and maximum allowable shipping period is given in Appendix 4.6.6 to illustrate, based on the methodology presented in this section.

4.5.1. Determination of Bounding G Values

The first step in performing a gas generation calculation is to determine the G values. As such, the following sections describe the steps in this process.

4.5.2. G Values for Water

G values for water are provided in Table 4.5-1 and are taken from NUREG/CR-6673 [Ref. 54], EPRI NP-5977 [Ref. 55], and RH-TRU Payload Appendices [Ref. 56].

Table 4.5-1 G values [Molecules/100 eV] for water

Material	G_H = $G_{(H2)}$	G_{FG} = $G_{(flammable\ gas)}$	G_T = $G_{(net\ gas)}$
Water (liquid phase, beta / gamma radiation)	0.45	0.45	0.45
Water (liquid phase, alpha radiation)	1.60	1.60	1.60

Only hydrogen gas was considered as a byproduct of the radiolysis of water. This results in the fraction of flammable gas to the total gas generated (α) of 1.0 in Equation 4.8 of NUREG/CR-6673 [Ref. 54]. Including oxygen in the total gas generation from the radiolysis of water would decrease the mole fraction of hydrogen (X_H) in the free gas volume. This is because the α term would be less than 1.0. Thus, using the value of α = 1.0 would yield the most bounding result.

4.5.2.1. *Calculation of effective G Values*

According to NUREG/CR-6673 [Ref. 54], the effective radiolytic G value for water can be expressed as the G value with some weighting factors for the energy absorbed:

$$G_{eff} = F_P \cdot F_W \cdot G_W$$

Where:

- F_P is the fraction of energy emerging from radioactive particles;
- F_W is the fraction of energy absorbed by water; and
- G_W is the maximum G value for water

Since determination of particle size distributions is difficult, conservatively, $F_P = 1$.

Since the package is loaded underwater and then drained with a dewatering criterion of 10%, it is assumed that 10% of the water mass, at most, is in the containment vessel.

To conservatively estimate the water mass inside the containment vessel, the mass, m, and the volume occupied by the content $V_{content}$, must be known.

With V_{cavity}, the volume of the containment vessel provided in Section 4.1.5, the volume occupied by water before draining is:

$$V_{load,W} = V_{cavity} - V_{content}$$

With a dewatering criterion of 10%, the volume of water after draining is:

$$V_{drain,W} = 0.1 \times V_{load,W}$$

Then, F_W is defined as the mass fraction of water in the total waste mass:

$$F_W = \frac{V_{drain,W} \cdot \rho_{water}}{m + V_{drain,W} \cdot \rho_{water}} = \frac{1}{\frac{m}{V_{drain,W} \cdot \rho_{water}} + 1} = \frac{1}{\frac{m}{0.1 \cdot (V_{cavity} - V_{content}) \cdot \rho_{water}} + 1}$$

Therefore:

$$G_{eff} = \left(\frac{1}{\frac{m}{0.1 \cdot (V_{cavity} - V_{content}) \cdot \rho_{water}} + 1} \right) \cdot G_W$$

NUREG/CR-6673 [Ref. 54] specifies that the effective G value for a waste material that contains radioactive nuclei that emit alpha, beta, and gamma radiation is:

$$G_{eff} = \lambda_\alpha \cdot G_{eff,\alpha} + \lambda_\beta \cdot G_{eff,\beta} + \lambda_\gamma \cdot G_{eff,\gamma}$$

where:

- λ_α is the fraction of the decay energy due to alpha decay;
- λ_β is the fraction of the decay energy due to beta decay;
- λ_γ is the fraction of the decay energy due to gamma decay.

Table 4.5-1 lists the G values for water depending on radiation. Since the G values of water are the same between beta and gamma radiations, the focus is made on the fraction of energy emitted by alpha radiation.

The effective G values have to be calculated with the equation below.

$$G_{eff} = \lambda_\alpha \cdot G_{eff,\alpha} + \lambda_{\beta/\gamma} \cdot G_{eff,\beta/\gamma}$$

$$G_{eff} = \left(\frac{1}{\frac{m}{0.1 \cdot \left(V_{cavity} - V_{content}\right) \cdot \rho_{water}} + 1} \right) \cdot \left(\lambda_\alpha \cdot G_{W,\alpha} + \lambda_{\beta,/\gamma} \cdot G_{W,\beta/\gamma}\right)$$

4.5.2.2. Operating Temperature G Value Adjustment

According to NUREG/CR-6673 [Ref. 54] Section 2.4.2, the radiolysis of water is temperature independent.

4.5.3. Hydrogen Gas Generation by Radiolysis

As described in Section 4.5, the gas generation analysis is performed assuming that all decay energy is absorbed in the waste or in water, maximizing the amount of gas generated through radiolysis. However, some gamma radiation emitted from the waste escapes the cavity and is absorbed in the cask's lead shielding material.

For the hydrogen generation evaluation, the RT-200 is treated as a single rigid non-leaking enclosure. Using Equation 4.8 of NUREG/CR-6673 [Ref. 54], the equation characterizing the mole fraction of hydrogen in the RT-200 over time for water generating hydrogen is shown below.

$$X_H = \frac{n_H}{n_0 + n_{net}} = \frac{\frac{D_H}{100} \cdot \frac{\alpha \cdot G_{eff,T} \cdot t}{A_N}}{\frac{P_0 V}{R_g T_0} + \frac{D_H}{100} \cdot \frac{G_{eff,T} \cdot t}{A_N}}$$

where:

- X_H = mole fraction of hydrogen,
- n_H = number of moles of hydrogen [gmol],
- n_0 = initial number of gas moles in the container when the vessel was closed [gmol],
- n_{net} = number of moles of gas generated [gmol],
- $G_{eff,T}$ = total radiolytic effective G value [molecules/100eV],
- D_H = decay heat that is absorbed by the radiolytic materials [eV/s],
- α = fraction of G_T that is equivalent to G_{FG}, flammable gas released,
- A_N = Avogadro's constant [$6.022 \cdot 10^{23}$ molecules/gmol],
- P_0 = pressure when the container is sealed [atm],
- T_0 = temperature when the container is sealed [K],
- V = container void volume [cm^3],

- R_g = gas law constant [82.05 $cm^3 \cdot atm/(gmol \cdot K)$],
- t = time [seconds]

Based on Section 4.4 of NUREG/CR-6673 [Ref. 54], shipping periods other than one year need to be defined as half the time it takes for hydrogen to accumulate in the package to a concentration equivalent to the lower flammability limit. To ensure that this is taken into consideration in the calculations, the equation above has been adjusted to incorporate a factor of 1/2 to calculate the shipping period required.

$$t_{max} = \frac{1}{2} \times \frac{\frac{P_0 V}{R_g T_0} \cdot X_H}{\frac{D_H}{100} \frac{G_{eff,T}}{A_N} \cdot (\alpha - X_H)}$$

The next step is to determine the values of the variables in this equation:

- X_H = 0.05 according to Section 4.4.1.1 of NUREG/CR-6673 [Ref. 54],
- $G_{eff,T}$: to be calculated (see Section 4.5.2.1),
- D_H: to be filled in by the operator [eV/s],
- α = 1, see Section 4.5.2,
- A_N = $6.022 \cdot 10^{23}$ molecules/gmol,
- R_g = 82.05 cm^3atm/gmolK,
- P_0: to be filled in by the operator [atm],
- T_0: to be filled in by the operator [K],
- $V_{content}$ = volume occupied by the content,
- V_{cavity} = volume of the containment vessel, see Section 4.1.5,
- V = void volume in the containment vessel,
  = 0.9*(V_{cavity} – $V_{content}$)
- t_{max} = maximum allowable shipping time [seconds]

The maximum shipping period, t_{max}, must be calculated for every shipment to demonstrate that, in every shipment condition, hydrogen gas generated in the package during t_{max} does not exceed 5% by volume (with a safety factor of 2) of the free gas volume in the containment system of the package.

Therefore, due to radiolysis, shipping period is limited to t_{max}.

Note that an application example of maximum allowable shipping period is given in Appendix 4.6.6 to illustrate, based on the methodology presented in this section.

4.6. APPENDIX

This appendix contains proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390. This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

4.6.1. List of References

This section provides a list of the documents that are referred to within Section 4 – “Containment”. The detailed list of the comprehensive SAR references can be found in Section 0 – “Introduction”.

Some of the references listed below might contain proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390: when it is the case, the reference is then clearly identified "(PROPRIETARY)". This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

Ref. 45 U.S. Nuclear Regulatory Commission, 10 CFR Part 71 – Packaging and Transportation of Radioactive Material

Ref. 46 ANSI N14.5-2022, “American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment”, American National Standards Institute, Inc., 11 West 42nd Street, New York, NY

Ref. 47 Frank M. White, “Viscous fluid flow”, 2nd edition

Ref. 48 NUREG/CR-6487, UCRL-ID-124822, “Containment Analysis for Type B Packages Used to Transport Various Contents”, B.L. Anderson et al., Lawrence Livermore National Laboratory, November 1996

Ref. 49 Robatel Industries, “RT-200 – Pressures Calculations”, Technical Note, RT-200 NTE 3003, Rev. C (PROPRIETARY)

Ref. 50 Glenn Lee, “Radiation Resistance of Elastomers”, IEEE Transactions on Nuclear Science, Vol. NS-32, No 5, October 1985

Ref. 51 Parker, O-Ring Handbook, ORD 5700, 2021

Ref. 52 Trelleborg Sealing Solutions, O-Ring and Backup Rings Catalog, October 2023 Edition

Ref. 53 James Walker, O-Ring Guide, Issue 7

Ref. 54 NUREG/CR-6673, “Hydrogen Generation in TRU Waste Transportation Packages”, Anderson, B., Sheaffer, M., & Fischer, L., Lawrence Livermore National Laboratory, Livermore, CA, May 2000

Ref. 55 EPRI NP-5977, “Radwaste Radiolytic Gas Generation Literature Review”, Electric Power Research Institute, September 1988

Ref. 56 “RH-TRU Payload Appendices”, Rev. 2, November 2013

4.6.2. Containment System and Boundaries: Illustrations and Data

Figure 4.6-1 Illustration of containment system and containment boundary

[redacted]

Table 4.6.2-1 Main Cask Cavity Dimensions

Main Dimensions		Values
Cavity inner length [cm]	L_{cavity}	457
Cavity inner diameter [cm]	D_{cavity}	110
Total cavity volume [cm^3]	$V_{cavity} = (\pi \cdot D_{cavity}^2 \cdot L_{cavity})/4$	$4.34 \cdot 10^6$

4.6.3. Elastomer Seal Temperature Specifications

4.6.3.1. Summary of Operating Temperature

Various manufacturers' data are available on the operating temperatures of elastomer seals.

This paragraph summarizes the operating temperatures from three different manufacturer's data documents presented in §4.6.3.2 and defines the temperature range selected for the studies and criteria defined in the SAR.

Table 4.6.3-1 Elastomer seals operating temperature

[redacted]

4.6.3.2. Manufacturers Elastomer Seals Working Temperature

(see following pages)

4.6.3.2.1. Parker Data [Ref. 51]

Parker

Parker O-Ring & Engineered Seals Division
2360 Palumbo Drive, Lexington, KY 40509
Phone: (859) 269-2351 • Fax: (859) 335-5128
www.parkerorings.com

Basic O-Ring Elastomers

Not compatible with:
- Fuels of high aromatic content (for flex fuels a special compound must be used).
- Aromatic hydrocarbons (benzene).
- Chlorinated hydrocarbons (trichloroethylene).
- Polar solvents (ketone, acetone, acetic acid, ethylene-ester).
- Strong acids.
- Brake fluid with glycol base.
- Ozone, weather and atmospheric aging.

2.2.2 Carboxylated Nitrile (XNBR)

Carboxylated Nitrile (XNBR) is a special type of nitrile polymer that exhibits enhanced tear and abrasion resistance. For this reason, XNBR based materials are often specified for dynamic applications such as rod seals and rod wipers.

Heat resistance
- Up to 100°C (212°F) with shorter life @ 121°C (250°F).

Cold flexibility
- Depending on individual compound, between -18°C and -48°C (0°F and -55°F).

Chemical resistance
- Aliphatic hydrocarbons (propane, butane, petroleum oil, mineral oil and grease, diesel fuel, fuel oils) vegetable and mineral oils and greases.
- HFA, HFB and HFC hydraulic fluids.
- Many diluted acids, alkali and salt solutions at low temperatures.

Not compatible with:
- Fuels of high aromatic content (for flex fuels a special compound must be used).
- Aromatic hydrocarbons (benzene).
- Chlorinated hydrocarbons (trichloroethylene).
- Polar solvents (ketone, acetone, acetic acid, ethylene-ester).
- Strong acids.
- Brake fluid with glycol base.
- Ozone, weather and atmospheric aging.

2.2.3 Ethylene Acrylate (AEM, Vamac)

Ethylene acrylate is a terpolymer of ethylene and methyl acrylate with the addition of a small amount of carboxylated curing monomer. Ethylene acrylate rubber is not to be confused with polyacrylate rubber (ACM).

Heat resistance
- Up to 149°C (300°F) with shorter life up to 163°C (325°F).

Cold flexibility
- Between -29°C and -40°C (-20°F and -40°F).

Chemical resistance
- Ozone.
- Oxidizing media.
- Moderate resistance to mineral oils.

Not compatible with:
- Ketones.
- Fuels.
- Brake fluids.

2.2.4 Ethylene Propylene Rubber (EPR, EPDM)

EPR copolymer ethylene propylene and ethylene-propylene-diene rubber (EPDM) terpolymer are particularly useful when sealing phosphate-ester hydraulic fluids and in brake systems that use fluids having a glycol base.

Heat resistance
- Up to 150°C (302°F) (max. 204°C (400°F)) in water and/or steam).

Cold flexibility
- Down to approximately -57°C (-70°F).

Chemical resistance
- Hot water and steam up to 149°C (300°F) with special compounds up to 260°C (500°F).
- Glycol based brake fluids (Dot 3 & 4) and silicone-basaed brake fluids (Dot 5) up to 149°C (300°F).
- Many organic and inorganic acids.
- Cleaning agents, sodium and potassium alkalis.
- Phosphate-ester based hydraulic fluids (HFD-R).
- Silicone oil and grease.
- Many polar solvents (alcohols, ketones, esters).
- Ozone, aging and weather resistant.

Not compatible with:
Mineral oil products (oils, greases and fuels).

2.2.5 Butyl Rubber (IIR)

Butyl (isobutylene, isoprene rubber, IIR) has a very low permeability rate and good electrical properties.

Heat resistance
- Up to approximately 121°C (250°F).

Cold flexibility
- Down to approximately -59°C (-75°F).

Chemical resistance
- Hot water and steam up to 121°C (250°F).
- Brake fluids with glycol base (Dot 3 & 4).
- Many acids (see Fluid Compatibility Tables in Section VII).
- Salt solutions.
- Polar solvents, (e.g. alcohols, ketones and esters).
- Poly-glycol based hydraulic fluids (HFC fluids) and phosphate-ester bases (HFD-R fluids).
- Silicone oil and grease.
- Ozone, aging and weather resistant.

Not compatible with:
- Mineral oil and grease.
- Fuels.
- Chlorinated hydrocarbons.

2-4

WARNING: These products can expose you to chemicals including carbon black (airborne and extracts), antimony trioxide, titanium dioxide, silica (crystalline), di(2-ethylhexyl) phthalate, ethylene thiourea, acrylonitrile, 1,3-butadiene, epichlorohydrin, toluenediisocyanate, tetrafluoroethylene, ethylbenzene, formaldehyde, furfuryl alcohol, glass fibers, methyl isobutyl ketone, nickel (metallic and compounds), lead and lead compounds which are known to the State of California to cause cancer; and 1,3-butadiene, epichlorohydrin, di(2-ethylhexyl)phthalate, di-isodecyl phthalate, ethylene thiourea, methyl isobutyl ketone, methanol, toluene, lead and lead compounds which are known to the State of California to cause birth defects and other reproductive harm. For more information go to www.P65Warnings.ca.gov.

4.6.3.2.2. Trelleborg Data [Ref. 52]

O-RING · Technical Information

TEMPERATURE RANGE

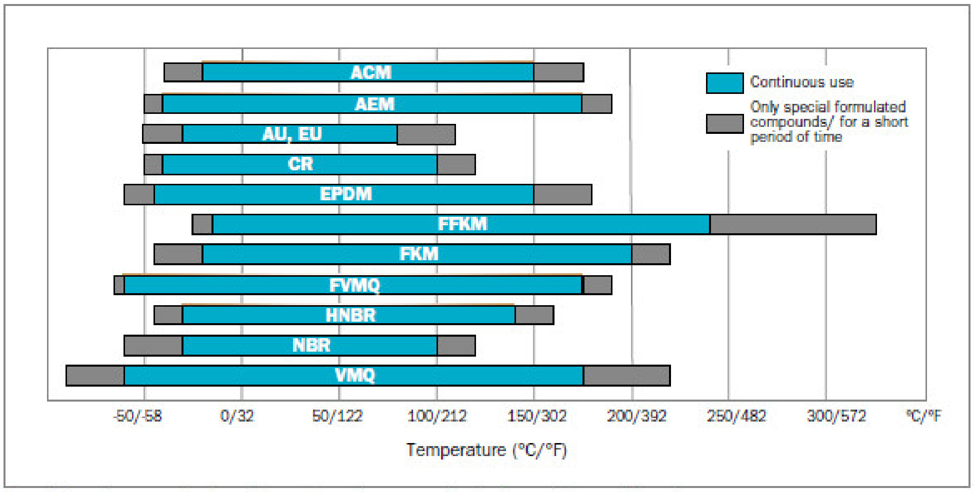

Figure 4: Temperature ranges of various elastomers. Temperature ranges only apply when used with compatible media.

Table 3: General field of application

Material and Properties	Applications	Operating Temperature Normal °C	Operating Temperature Normal °F	Short period °C	Short period °F
ACM (Polyacrylate Rubber) - Excellent resistance to ozone, weathering and hot air, although it shows only a medium physical strength - Low elasticity - Relatively limited low temperature capability	ACM is used in automotive applications which require special resistance to lubricants containing many additives (incl. sulfur) at high temperatures	-20 to +150 (special types -35 to +150)	-4 to +302 (special types -31 to +302)	up to +175	up to +347
CR (Chloroprene Rubber) - Good resistance to ozone, weathering, chemicals and aging - Good non-flammability - Good mechanical properties and cold flexibility.	CR is used in sealing applications involving refrigerants, outdoor applications and in the glue industry	-35 to +90 (special types -55 to +90)	-31 to +194 (special types -67 to +194)	up to +120	up to +248
EPDM (Ethylene Propylene Diene Rubber) - Good heat, ozone and aging resistance - High levels of elasticity - Good low temperature behavior - Good insulating properties.	EPDM can often be found in applications with brake fluids (based on glycol) and hot water	Peroxide cured EPDM Types			
		-45 to +150	-49 to +302	up to +175	up to +347
		Sulfur cured EPDM Types			
		-45 to +130	-49 to +266	up to +150	up to +302

32 · TRELLEBORG SEALING SOLUTIONS

Latest information available at www.trelleborg.com/seals · Edition October 2023

4.6.3.2.3. James Walker Data [Ref. 53]

James Walker

Materials & properties

Guide to material use

MATERIAL TYPE		Air or oxygen	Water – up to 80°C	Water – above 80°C	Dilute acids	Dilute alkalis	Lower alcohols	Aldehydes	Amines	Chlorinated solvents	Ethers	Ketones	Hydrocarbons – aliphatic	Hydrocarbons – aromatic	Leaded petrol (gasoline)	Kerosene	Animal oils and fats	Fuel oils and diesel oils	Lubricating oils – mineral	Lubricating oils – synthetic	Silicone oils and grease	Vegetable oils	Hydraulic fluids – mineral based	Hydraulic fluids fire resistant: Chlorinated	Oil in water emulsions	Water in oil emulsions	Water – glycol based	Phosphate esters – aliphatic	Phosphate esters – aromatic	Temperature range (°C): Low	High – continuous	High – intermittent	Hardness range IRHD	Available to the latest issue of the following specifications
Acrylic	ACM	2	4	4	4	4	4	4	4	3	3	4	1	3	1	1	1	1	1	2	1	1	1	4	4	4	4	4	4	–20	150	175	80	
Aflas*	FEPM	1	1	1[F]	1	1	1	1	1	3	4	4	1	3	2	1	1	1	1	2	1	1	1	2	1	1	1	1	2	0	200	230[F]	70 - 90	
Butyl	IIR	1	1	2	1	1	1	1	1	4	4	1	4	4	4	4	2	4	4	4	1	3	4	4	4	4	1	2	2	–35	120	150	60 - 70	BS 3227
Chlorosulphonyl polyethylene	CSM	2	1	3	4	1	1	3	4	4	4	4	3	4	4	4	3	3	4	4	1	2	2	4	4	3	1	4	4	–30	120	150	65 - 80	
Elast-O-Lion*	HNBR	1	1	1	1	2	1	2	1	2	4	4	1	3	2	1	1	2	1	1	1	1	1	4	2	2	2	3	4	–25[A]	150	170	50 - 90	DEF STAN 02-337
Epichlorohydrin	ECO	2	1	2	3	2	2	4	1	4	4	4	3	4	1	1	1	1	1	4	1	1	1	4	2	2	2	4	4	–30	150	175	70 - 90	
Ethylene-propylene	EPM/EPDM	1	1	1	2	1	1	1	2	4	3	1	1	4	4	4	2	4	4	4	1	3	4	4	4	4	1	1	2	–45	120	150[B]	50 - 90	BS F 156, 162
Fluolion*	PTFE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	–200	250			
Fluoroelastomers	FKM	1	1	3	1	2	4[C]	4[C]	4[C]	1	3[C]	4[C]	1	1	1	1	1	1	1	2	1	1	1	2	1	1	2	1	1	–15[D]	200	230[D]	50 - 98	DEF STAN 02-337, *DTD 5543, 5603, 5612, 5613.
Fluorosilicone	FVMQ	1	1	2	3	2	1	4	4	2	3	4	1	1	2	1	1	2	1	2	1	1	2	2	2	2	2	3	3	–60	180	200	60 - 80	BS F 154
Kalrez*	FFKM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	–40	325		70 - 95	SAE AMS 7257
Natural rubber	NR	3	1	2	3	2	2	3	2	4	4	4	4	4	4	4	4	4	4	4	1	4	4	4	4	4	3	4	4	–50	100	120	40 - 85	BS 1154
Neoprene	CR	1	1	2	3	1	1	3	2	4	4	4	2	4	3	2	2	3	2	3	1	3	3	4	4	4	3	4	4	–40	120	150	40 - 90	BS 2752
Nitrile	NBR	2	1	2	3	2	1	3	2	3	4	4	1	3	2	1	1	2	1	2	1	1	1	4	3	3	1	4	4	–30[A]	120	150	40 - 90	BS 2751, 6996, 6997, DEF STAN 02-337, *DTD 5509, 5594, 5595, 5606, 5607.
Polyurethane	AU/EU	1	4	4	4	4	4	4	4	3	2	4	2	4	2	2	2	3	2	4	1	2	1	4	4	4	4	4	4	–15	85	100	55 - 95[E]	
Silicone	VMQ	1	1	2	3	2	1	2	2	4	4	3	3	4	4	4	2	4	3	3	4	1	4	3	3	4	2	2	3	–65	200	250	40 - 80	BS F 152, 153, 159

Key

1 Very good
2 Good
3 Fair
4 Not recommended

* These specifications have been declared OBSOLESCENT.
[A] Low acrylonitrile content grades are available for temperatures down to -46°C.
[B] EPM grades are available for hot water service up to +180°C.
[C] Fluoroelastomer grades are available that offer resistance to these chemicals.
[D] Fluoroelastomer grades are available for temperatures down to -41°C and up to +250°C intermittent.
[E] Polyurethane grades are also available in hardnesses from 60 to 74 Shore D.
[F] Some Aflas® grades will work at temperatures to +260°C in hot water and steam.

***Note:** These figures are for guidance only. Service life will depend on type of application, whether static or dynamic, specific pressure medium, temperature cycle, time of exposure, etc. In general, the low temperatures quoted are at atmospheric pressure and may change at elevated pressures.*

Service grades

'O' rings precision moulded by James Walker are supplied with quality acceptance criteria as follows:

- **Standard supply: Grade N** of BS ISO 3601-3 *Fluid power systems — O-rings — Part 3: Quality acceptance criteria.*
- **Grade S:** This higher grade is provided when required — typically for aerospace, critical industrial or automotive applications.
- **Grade CS** (Critical Services) is also available. This is typically for critical aerospace and medical duties. Please discuss your requirements with our Technical Support Team.

Commercial quality 'O' rings *(page 25)* and items in our 'O' ring kits *(page 26)* are normally supplied to Grade N.

Note: For cross sections below 0.8mm or above 8.4mm, please contact our Technical Support Team.

10 **To order or get further details, call your local contact shown on rear cover or listed at www.jameswalker.biz**

4.6.4. Elastomer Seal Characteristics with Respect to Damage by Hardness Concerns (from [Ref. 52])

B.1.3 CHARACTERISTICS AND INSPECTION OF ELASTOMERS

Hardness
One of the most frequently named properties regarding polymer materials is hardness. Even so, the values can be quite misleading.

Hardness is the resistance of a body against penetration of an even harder body of a standard shape at a defined pressure.

There are two procedures for hardness tests regarding test samples and finished parts made out of elastomer materials:

1. Shore A / D in accordance with ISO 868 / DIN ISO 48-4 / ASTM D 2240 - Measurement for test samples
2. Durometer IRHD (International Rubber Hardness Degree) in accordance with ISO 48 / ASTM 1414 and 1415 - Measurement of test samples and finished parts

The hardness scale has a range of 0 (softest) to 100 (hardest). The measured values depend on the elastic qualities of the elastomers, especially on the tensile strength.

The test should be carried out at temperatures of 23 ±2 °C (73.4 ±2 °F) - not earlier than 16 hours after the last vulcanization process (manufacturing stage). If other temperatures are being used this should be mentioned in the test report.

Tests should only be carried out with samples which have not been previously stressed mechanically.

Hardness tests in accordance with Shore A / D
The hardness test device Shore A (indentor with pyramid base) is a sensible application in the hardness range 10 to 90. Samples with a larger hardness should be tested with the device Shore D (indentor with spike).

Test specimen:
Diameter min. 30 mm (1.181 inch)
Thickness min. 6 mm (0.240 inch)
Upper and lower sides smooth and flat

When thin material is being tested it can be layered to ensure a minimum sample thickness is achieved, up to a maximum of 3 layers. All layers must be at minimum 2 mm (0.080 inch) thick.

The measurement is done at five different places at a defined distance and time.

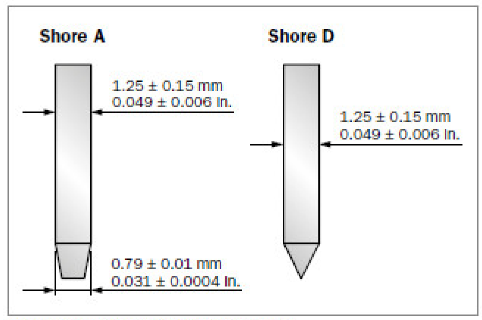

Figure 5: Indentor in accordance with Shore A / D

Hardness test in accordance with IRHD
The test of the Durometer in accordance with IRHD is used with test samples as well as with finished goods.

The thickness of the test material has to be adjusted according to the range of hardness. In accordance with ISO 48, there are two hardness ranges:

Soft:	10 to 35 IRHD	⇒ Sample thickness 10 to 15 mm (0.394 to 0.591 inch) procedure "L"
Normal:	over 35 IRHD	⇒ Sample thickness 8 to 10 mm (0.315 to 0.394 inch) procedure "N"
		Sample thickness 1.5 to 2.5 mm (0.059 to 0.098 inch) procedure "M"

The hardness determined with finished parts or samples can vary from those determined from specimen samples, especially those with a curved surface.

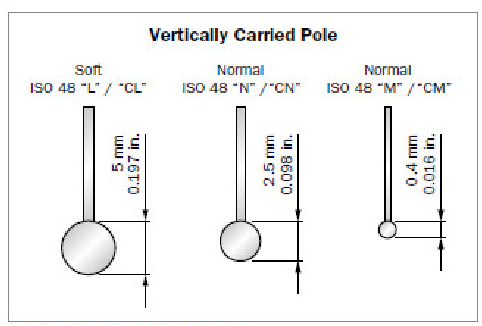

Figure 6: Indentor in accordance with IRHD

Influencing parameters on the hardness test for polymer materials
Various sample thicknesses, geometries and testing procedures can show different hardness values even though the same materials have been used.

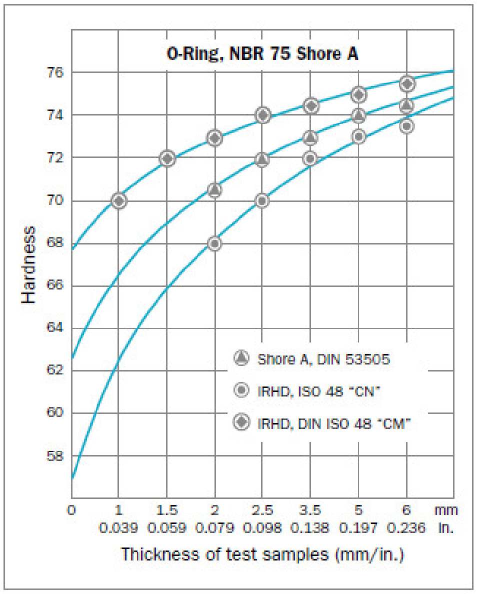

Figure 7: Ranges of hardness depending on sample thickness and test method

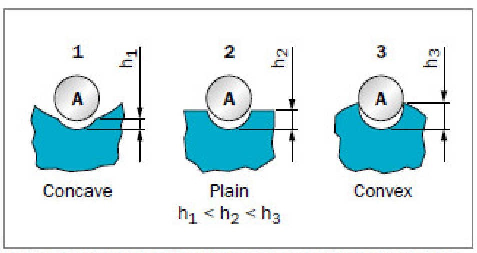

Figure 8: Range of hardness depending on surface geometry for the equivalent material characteristics

With equivalent material characteristics of the elastomer sample 3, the indentor penetrates the deepest at the surface (Figure 8) and therefore establishes the softest area.

As the convex geometry has a stronger effect on smaller width O-Rings, the tolerances on hardness for widths under 2.0 mm (0.079 inch) should be increased up to +5 / -8 IRHD based on the valid IRHD nominal value.

Compression set
An important parameter regarding the sealing capability is the compression set (CS) of the O-Ring material. Elastomers when under compression also show permanent plastic deformation (Figure 9).

The compression set is determined in accordance with ISO 815 as follows:

Standard test piece:	Cylindrical disc, diameter 13 mm (0.512 inch) and height 6 mm (0.236 inch)
Deformation:	25%
Tension release time:	e.g. 30 minutes

$$CS = \frac{h_0 - h_2}{h_0 - h_1} \cdot 100 [\%]$$

Where h_0 = Original height (cross section d_2)
h_1 = Height in the compressed state
h_2 = Height after tension release

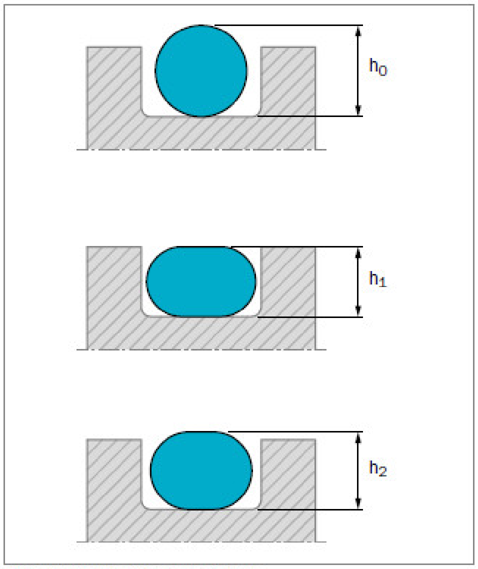

Figure 9: Illustration of the compression set

The accuracy of the measured value depends on:

- Test sample thickness
- Deformation
- Measurement deviations

Therefore the values which have been identified with the test sample cannot be transferred onto the finished part. The result of the measured finished parts are strongly influenced by geometry and measurements as well as the measuring accuracy of the test equipment.

Figure 10 shows the influence of various measuring deviations (in mm) in respect to the established compression set (CS) depending on the cross section of the measured O-Rings.

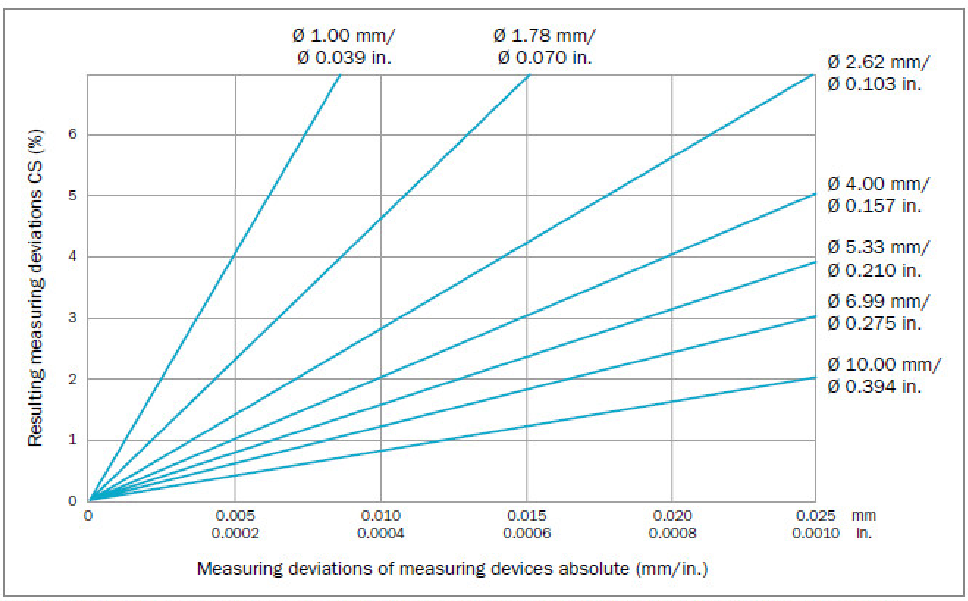

Figure 10: Compression set measuring deviations depending on O-Ring cross section and measuring accuracy of the test equipment (schematic illustration)

4.6.5. Additional Information about Elastomer Seal Resistance to Radiation [Ref. 50]

3806

IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

RADIATION RESISTANCE OF ELASTOMERS

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Batavia, Illinois 60510

Abstract

Various data has indicated that some elastomers have much higher radiation resistance than Viton. Nine samples of elastomers were irradiated with gamma rays. Two Ethylene Propylene Diene compounds, EPDM's, were found to exhibit acceptable properties for o-rings after radiation levels of 5×10^8 rads, while Viton failed at 1×10^7 rads. Vacuum tests also were favorable so EPDM o-rings were chosen as seals in the Energy Saver cryostat vacuum system.

Introduction

Viton is commonly used for o-ring seals in high vacuum systems, and failures have occurred in radiation areas such as particle beam transport lines due to radiation from beam loss. In a search for radiation resistant seals suitable for vacuum systems, nine elastomer samples were obtained from Minnesota Rubber Company and irradiated with gamma rays.

Materials Tested

The samples tested were:

Compound #	
559N	EPDM (Ethylene Propylene Diene)
559EQ	EPDM (Ethylene Propylene Diene)
366T	NBR (Nitrile)
514AD	Viton
71417	Silicone
512AJ	Sulfur Cured Urethane
482BJ	Neoprene
560ND	EPDM (tightly cured)
564FP	Peroxide Cured Urethane
564FB	Sulfur Cured Urethane

Affect of Radiation

Minnesota Rubber Company tested the elastomers after irradiation. There are some variances of data due to the size of the samples tested and the results are as follows.

The compound, 512AJ, sulfur cured Urethane, appears to have the best radiation resistance. Even after 10^9 rads 512AJ has some elongation and tensile and little change in hardness. However, the compression set of 512AJ, even originally, is poor which is typical of sulfur cured Urethanes. In a seal application, compression set is a critical property and such extremely poor set resistance will cause part failure.

The EPDM compounds 559N and 559EQ show the best all around properties with radiation levels up to 5.0×10^8 rads. They exhibit good tensile and are still elastomeric though elongation is low and hardness is high. Compression set is excellent even at 5.0×10^8 rads. The EPDM's are not good at levels of 10^9 rads since in the compression set test both samples disintegrated.

The other compounds were brittle at or before 3.0×10^8 rads. Compound 366Y, a NBR, retains good properties at 10^8 rads. Compound 482BJ, a Neoprene; was brittle at 3×10^8 rads though it had good properties at 10^8 rads. Both 71417, silicone, and 514AD, Viton, were significantly affected by the radiation, becoming hard even at 5×10^7 rads and brittle at 3×10^8 rads.

For all radiation applications up to 5.0×10^8 rads the best compounds are 559N or 559EQ, the EPDM's. If radiation levels are higher than 5.0×10^8 rads, then compound 512AJ could be used, but difficulty would be encountered in designing a functional part because of the high set it exhibits.

The test results confirmed that EPDM compounds have the best all around properties with radiation levels up to $.5\times10^9$ rads. They retain reasonable flexibility and strength, hardness, and very good compression set resistance.

A Urethane that is sulfur cured has the best flexibility, strength and hardness even up to 2×10^9 rads. However, they have very poor compression set qualities even before treatment of radiation. The sulfur cured Urethane fail completely by $.85\times10^9$ rads in compression set.

The peroxide cured Urethanes have an initial change of properties but seem to stabilize through to 2.0×10^9 rads and is very brittle at 3×10^9 rads. The initial compression set characteristics is much better than the sulfur cured Urethanes but again failure is seen at $.85\times10^9$ rads.

There are many new compounds now that have not been tested. Quite possibly elastomers with properties superior to the EPDM's could be found.

Vacuum Tests at Fermilab

Urethane o-rings have been used for a few vacuum applications in high radiation areas, but extreme outgassing eliminated their use in high vacuum apparatus. Samples of compounds 560ND, 564FB, 564FP, Viton, and polyurethane cord purchased from Eagle Belting Company were tested for outgassing in a very simple vacuum chamber. The chamber consisted of a spare Fermilab main ring ion pump with a short tube extension and a roughing valve. Equal weights of elastomer samples were placed in the tube extension and the chamber was then roughed down and the ion pump started. The ion pump power supply frequency was used as the pressure indicator since an ion gauge was not available. A frequency of 10 KHz indicated a pressure of approximately 1×10^{-8} Torr. A table of test results indicates the extreme outgassing of the Urethane materials as compared to Viton, while the ethylene propylene compound wasn't so bad. No data was obtained as to actual outgassing rates due to lack of personnel, time, and equipment.

Figure 1 shows the pump-down data for six of the compounds tested. Figures 2,3,4, and 5 shows respectively, the elongation, compression set, tensile, and hardness properties.

*Operated by Universities Research Association, Inc. under contract with the U.S. Department of Energy.

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Results

As a result of this investigation, ethylene propylene o-rings were ordered and used in the cryostat vacuum system for the Energy Saver. The EPDM O-rings performed satisfactorily but they are slightly permeable to helium, very similar to neoprene. This has to be noted when leak checking.

Acknowledgements

Thanks to Joe Schuchman of Brookhaven National Laboratory and Tom Kiedrowski of Minnesota Rubber Company for their help in obtaining this data.

ELASTOMER OUTGASSING TEST

MATERIAL	START ROUGHING	START ION PUMP	END OF 1st HR.	END OF 2nd HR.	END OF 3rd HR.	END OF 4th HR.
ION PUMP (clean up)	1035	1040	5×10^{-7} TORR	2×10^{-7} TORR		
COMPOUND 560ND	1243	1258	15.5 KHz	10.5 KHz	9 KHz 9×10^{-6}	7.3 KHz 7×10^{-6}
ION PUMP (clean up)	0850	0855	3×10^{-7}	1×10^{-7}		
COMPOUND 564FR POLYURETHANE	1255	1315	28 KHz	27 KHz	27 KHz	27 KHz
ION PUMP (clean up)	0855	0905	4×10^{-7}	2×10^{-7}		
COMPOUND 564FP	1110	1125	28 KHz	26 KHz	26 KHz	26 KHz
VITON	0840	0855	10 KHz 1×10^{-5}	4×10^{-6}	3.0 KHz 3×10^{-6}	2.5 KHz 2.5×10^{-6}
ORANGE POLYURETHANE	1255	1315	28 KHz	25 KHz	23 KHz	17.7 KHz

Fig. 1: Relative outgassing of elastomers. A frequency of 10 KHz indicates a pressure of 1×10^{-5} Torr, and pressures noted were taken from a pressure vs. frequency curve.

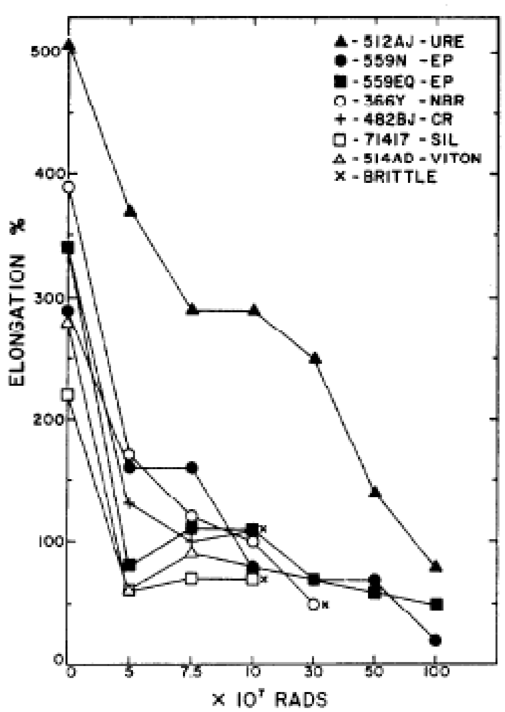

Fig. 2: Elongation of elastomers after irradiation.

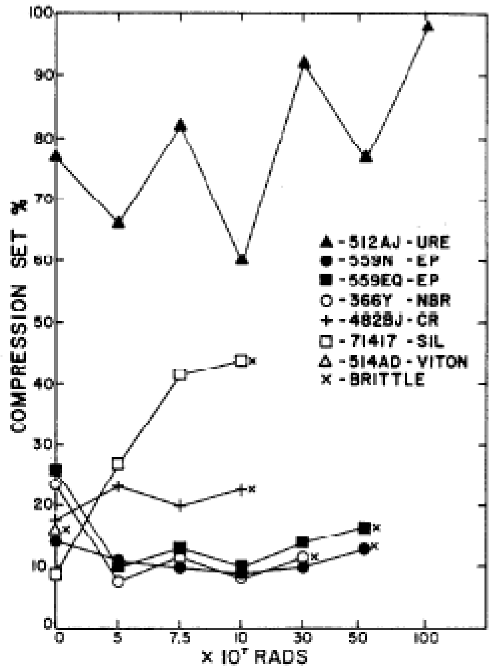

Fig. 3: Compression set for elastomer materials after irradiation.

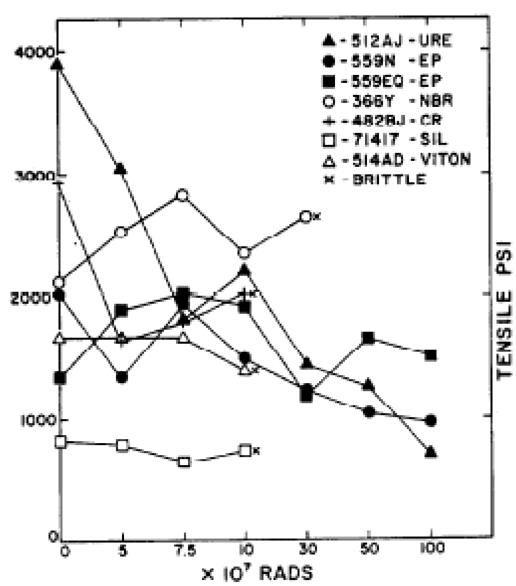

Fig. 4: Tensile strength of elastomers after irradiation.

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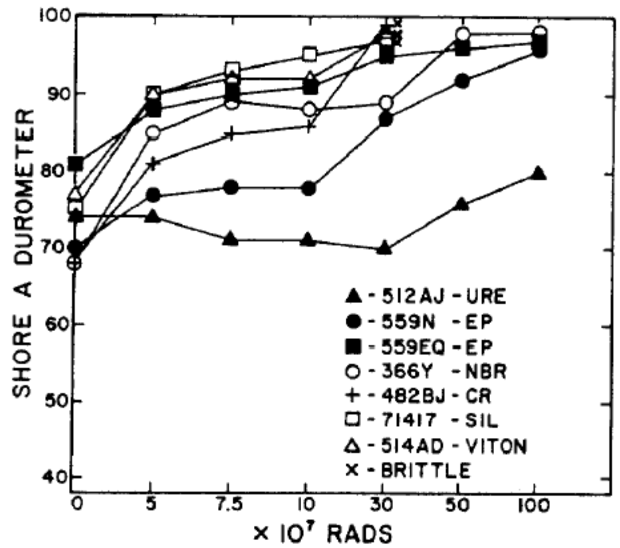


Fig. 5: Shore durometer hardness of elastomers after irradiation.

4.6.6. Example of Hydrogen Gas Generation Calculation

Determination of maximum shipping period with the following initial conditions:

- Content is loaded under water
- m = payload mass = 8,100 kg
- ρ = mean density of payload = 7.5 g/cm^3
- D_H = decay heat absorbed by the radiolytic materials [eV/s] = 300 W = $1.87245 \cdot 10^{21}$ eV/s
- P_0 = pressure when the container is sealed = 1 atm
- T_0 = temperature when the container is sealed = 298 K
- λ_α is the fraction of the decay energy due to alpha decay = 0.01
- $\lambda_{\beta/\gamma}$ is the fraction of the decay energy due to beta and gamma decay = 0.99

<u>**Step 1**: Calculation of effective G values.</u>

According to Section 4.5.2.1,

$$G_{eff} = \left(\frac{1}{\frac{m}{0.1 \cdot \left(V_{cavity} - V_{content}\right) \cdot \rho_{water}} + 1} \right) \cdot \left(\lambda_\alpha \cdot G_{W,\alpha} + \lambda_{\beta/\gamma} \cdot G_{W,\beta/\gamma}\right)$$

$$G_{eff} = \left(\frac{1}{\frac{8100 \cdot 10^3}{0.1 \cdot \left(4.34 \cdot 10^6 - \frac{8100 \cdot 10^3}{7.5}\right) \cdot 1} + 1} \right) \cdot (0.01 \cdot 1.60 + 0.99 \cdot 0.45)$$

Thus, effective G values for water [molecules/100 eV]:

$$G_{eff} = G_{eff.H} = G_{eff.FG} = G_{eff.T} = 1.846 \cdot 10^{-2}\ Molecules/100\ eV$$

<u>**Step 2**: Calculation of the maximum allowable shipping period.</u>

According to section 4.5.3.

$$t_{max} = \frac{1}{2} \times \frac{\frac{P_0 * 0.9 \cdot (V_{cavity} - V_{content})}{R_g T_0} \cdot X_H}{\frac{D_H}{100} \frac{G_{eff,T}}{A_N} \cdot (\alpha - X_H)}$$

The next step is to determine the values of the variables in this equation:

- X_H = 0.05 according to Section 4.4.1.1 of NUREG/CR-6673 [Ref. 54],
- $G_{eff,T}$ = $1.846 \cdot 10^{-2}$ Molecules/100 eV,
- D_H = 300 W = $1{,}87245 \cdot 10^{21}$ eV/s,
- α = 1, see Section 4.5.2,
- A_N = $6.022 \cdot 10^{23}$ molecules/gmol,
- R_g = 82.05 $cm^3 \cdot atm/(gmol \cdot K)$,
- P_0 = 1 atm,
- T_0 = 298 K,
- $V_{content}$ = volume occupied by the content
  = m/ρ
- V_{cavity} = volume of the containment vessel, see Table 4.6.2-1,
- t_{max} = maximum allowable shipping time [seconds]

Numerically, $t_{max} = 5.38 \cdot 10^6$ s = 62.3 days

Therefore, it shows that, in the initial conditions presented for this example, hydrogen gas generated in the package during a period of 62 days will not exceed 5 % by volume (with a safety factor of 2) of the free gas volume in the containment system of the package.

Therefore, due to radiolysis, in this example, the shipping period would be limited to 62 days.

5. SHIELDING

This Chapter describes the RT-200 shielding evaluation and summarizes the results to demonstrate compliance with the shielding requirements of 10 CFR 71 [Ref. 57]. The RT-200 cask package is designed to transport:

- Content No. 1: solid irradiated and contaminated non-fuel-bearing materials and Stellite Boxes in Storage Containers, and
- Content No. 2: Miscellaneous solid irradiated and contaminated non-fuel-bearing hardware in secondary containers.

The RT-200 has a robust gamma shielding design comprised of a steel/lead/steel body with a steel lid bolted onto the body. The lid along with its O-ring seals provide secure containment of the radioactive material contents. Analyses presented in this chapter demonstrate that the shielding design produces dose rates below the external radiation requirements of 10 CFR 71 [Ref. 57] under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). The package and vehicle radiation limits are for exclusive use of an open (flat-bed) transport vehicle.

The RT-200 is designed in compliance with the external radiation standards that are specified in 10 CFR 71 [Ref. 57] as:

- The RT-200 is designed, constructed, and prepared for shipment so that the external radiation levels will not significantly increase under the tests specified in 10 CFR 71.71 (Normal Conditions of Transport) in accordance with 10 CFR 71.43(f) and 10 CFR 71.51(a)(1).
- Under NCT tests specified in 10 CFR 71.71, the external radiation levels meet the requirements of 10 CFR 71.47(b) for exclusive-use shipments.
- Under HAC tests specified in 10 CFR 71.73, the external radiation level does not exceed 10 mSv/h (1 rem/h) at one meter from the surface of the package in accordance with 10 CFR 71.51(a)(2).

The shielding evaluation is based on the descriptions and evaluations presented in the General Information, Structural Evaluation and Thermal Evaluation sections of the application. Results of the shielding evaluation are considered in the preparation of Operating Procedures and the Acceptance Tests and Maintenance Program.

Different approaches are used to calculate the maximum allowable limits, depending on the content. Content No. 1 is based on limiting external radiation, to be operationally monitored, as defined in 10 CFR 71.47 [Ref. 57]. Content No. 2 shielding analysis is assessed using limitative Co-60 specific activity and doing a Co-60 equivalence to allow gamma emitting nuclides that are not Co-60 in the cask for transportation.

Table of Content

5.1. DESCRIPTION OF SHIELDING DESIGN

A description of the shielding design, as well as a summary of the results of the analysis for this design is provided below.

5.1.1. Design Features

The RT-200 body is a right circular cylinder whose inner cavity and overall dimensions are listed in Table 1.3-2.

In regard to gamma shielding, the RT-200 cask shielding is created by the thicknesses of stainless-steel and lead of the constituent elements of its body, detailed in Table 1.3-3. In particular:

- the inner shell,
- the outer shell,
- the lead between the inner and outer shell,
- the thermal shield plate,
- the rear forging,
- the lid.

Under transport conditions, the top and bottom impact limiters provide additional gamma shielding after the inner steel casing.

Dimensional tolerances and material densities used in the shielding evaluations are given in Section 5.3.1 and Section 5.3.2, respectively.

During normal conditions of transport, shielding evaluations assume that the RT-200 is transported on a truck trailer that is 2,430 mm wide and whose length enable to tie it down, in the center of the package, further than 2 meters from the end of the package. Thus:

- the 2-meter radial surface is 3,215 mm from the cask centerline.
- the distance to the cab, is met at 4 meters from the front of the package.
- the 2-meter distance from the rear of the vehicle is met at 3 meters from the rear of the package.

For Content No. 1, the dedicated basket shores the disposable insert in place and prevents it from shifting during transportation. The Disposable Inserts shore the Storage Containers in place. The Storage Containers shore the content in place.

5.1.2. Summary Table of Maximum Radiation Levels

The transport regulations provide dose limits in 10 CFR 71.47 and 71.51 [Ref. 57] at locations external to the package for rates for both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). A full discussion of the methods employed to analyze the RT-200 cask design and results of applying these methods that demonstrate compliance with the regulatory limits are presented in the sections that follow.

Table 5.1-1 shows the limiting external radiation, to be operationally monitored, as defined in 10 CFR 71.47 [Ref. 57], for Content No. 1. The cask operator must follow the procedures outlined in Chapter 7 to ensure these limits are respected.

Table 5.1-2 summarizes, for Content No. 2, the calculated results for the maximum radiation levels allowed for exclusive use shipment using an open (flat-bed) transport vehicle under NCT and HAC for the worst-case loading of radionuclides. These results represent the maximum dose rates for the worst-case allowable contents as presented in Section 5.4.4.

Table 5.1-1 : RT-200 Content No. 1: Summary of limiting external radiation

[redacted]

Table 5.1-2 : RT-200 Content No. 2: Summary of maximum dose rates

[redacted]

5.2. SOURCE SPECIFICATION

5.2.1. Gamma Source

5.2.1.1. Content No. 1

Content No. 1 of the RT-200 cask consists of 3 Storage Containers (SCs), described in Section 1.2.2.1.

The maximum total activity of Content No. 1 (including 3 SCs) is limited to 30,000 Ci = $1.11 \cdot 10^{15}$ Bq and 3,000 A_2.

Co-60 is the principal gamma emitter nuclide within the SC's content that overwhelmingly participates in the maximum radiation levels around an SC with a contribution greater than 99%.

The quantity of radioactive material within the RT-200 for Content No. 1 is limited by the maximum amount of radioactive material that corresponds to the external radiation standards as defined in 10 CFR 71.47 [Ref. 57]. The cask operator must follow the procedures outlined in Chapter 7 to ensure personnel safety and regulatory compliance.

5.2.1.2. Content No. 2

[redacted]

5.2.2. Neutron Source

[redacted]

5.2.3. Beta Source

[redacted]

5.3. Shielding Model

5.3.1. Configuration of Source and Shielding

5.3.1.1. Source term

5.3.1.1.1. <u>Content No. 1</u>

The quantity of radioactive material within the RT-200 for Content No. 1 is limited by the maximum amount of radioactive material that corresponds to the external radiation standards as defined in 10 CFR 71.47 [Ref. 57]. The cask operator must follow the procedures outlined in Chapter 7 to ensure compliance with these limits.

5.3.1.1.2. <u>Content No. 2</u>

Content No. 2 of the RT-200 consists of solid irradiated and contaminated hardware packed in secondary containers. The MCNP® model that represents Content No. 2 is a right circular cylinder of stainless-steel whose dimensions are summed-up in [Ref. 59]. The associated source term consists of:

[redacted]

The NCT and HAC shielding models consider the photon source uniformly distributed throughout the inner cavity. [redacted]

5.3.1.2. NCT model

This section provides a description of the MCNP® model of the RT-200 packaging that was developed to conduct the shielding calculations related to the NCT.

This model represents accurately the main parts of the cask in accordance with the design drawing [Ref. 58]. Key thicknesses for the cask and impact limiters are shown in Table 1.3-3.

Adjustments and simplifications have been made according to the main assumptions and to the main principles listed hereafter. From a general point of view, simplifications and adjustments aim to improve the computation efficiency by keeping the model conservative regarding the actual cask performance. They are defined consistently with safety issues to be addressed.

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

5.3.1.3. HAC model

This section provides a description of the MCNP® model of the RT-200 packaging that was developed to conduct the shielding calculations related to the HAC.

In addition to the NCT model, the main adjustments and simplifications that are considered for the MCNP® model for HAC are:

- Puncture test cannot result in a decrease of the thicknesses of the package shielding layers since:
  - impact limiter contribution is neglected: their potential damages do not affect the NCT findings in terms of dose rates level;
  - outer shell of the packaging body is not perforated: its potential local bump (see section 2.7.3.2.3) does not affect the NCT findings in terms of dose rates level.
- For the same reason, the impact limiter damage that would result from either the HAC fire test or the 9 m drop test does not affect the NCT findings in terms of dose rate levels.
- A 9 meter axial drop test on the rear end of the package could result in an axial slump in the lead shielding layer of the body. In such a case, an annular gap would be generated under the front or rear forging of the package body and is modeled in the HAC model.

5.3.2. Material Properties

Table 5.5-4 in appendix 5.5.7 lists the standard material compositions used within the MCNP® model. They are taken from [Ref. 61].

These compositions are used for all materials used within the model, but as detailed below, part densities are adjusted. The MCNP® model of the RT-200 cask relies on the nominal geometry according to drawing data. The effect of potential tolerances on the part dimensions is considered to reduce their material densities. In appendix 5.5.7, Table 5.5-5 sums up this information and Figure 5.5-7 illustrates it.

5.4. SHIELDING EVALUATION

5.4.1. Methods

MCNP6.2 [Ref. 62] is used to perform the shielding evaluation of the RT-200. The ENDF/B-VI Release 8 Photo-atomic Data gamma cross-section library, and MCPLIB84 [Ref. 63], are utilized in the transport computations.

MCNP® is a Monte Carlo transport code that offers a full three-dimensional combinatorial geometry modeling capability. This type of modeling means that no gross approximations are required to represent the RT-200 Cask in the shielding analysis.

Bounding shielding material thicknesses are used in the MCNP® models. The mesh based weight windows approach was utilized as a variance reduction technique in the shielding evaluation of the RT-200.

The aim of the calculations is to assess the maximum external dose rates around the RT-200 package in transport conditions when it is loaded with its contents.

5.4.2. Input and Output Data

All relevant inputs and outputs for the gamma and neutron shielding analysis are provided with calculation package CN-103622-501 [Ref. 66].

5.4.3. Flux-to-Dose-Rate Conversion

MCNP® calculates a photon flux (particles/s/cm²) at a particular tally or detector location given the source magnitude. These values are converted into doses by use of flux-to-dose response functions. This conversion is done internally in MCNP® by associating dose response functions to each tally in the input file. The gamma flux-to-dose and neutron flux-to-dose response functions used in these calculations are listed respectively in Table 5.5-2 and Table 5.5-3 [Ref. 64].

5.4.4. External Radiation Levels

[redacted]

5.4.4.1. Content No. 2

[redacted]

Table 5.4-1 : RT-200 Content No. 2: Maximum dose rates (1 TBq normalized source)

[redacted]

[redacted]

5.4.4.2. Content No. 1

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

5.4.4.3. Neutron and Secondary Gammas

[redacted]

[redacted]

[redacted]

[redacted]

Table 5.4-2 : RT-200 neutron source: neutron dose rates

[redacted]

Table 5.4-3 : RT-200 neutron source: secondary gammas dose rates

[redacted]

5.4.4.4. Beta Emission and Bremsstrahlung Effect

[redacted]

[redacted]

5.4.4.5. Self-shielding versus Source Distribution

[redacted]

[redacted]

Table 5.4-4 : RT-200 Content No. 2 – density = 1.865: Summary of maximum dose rates

[redacted]

[redacted]

5.4.4.6. *Shielding Evaluation Uncertainty*

[redacted]

[redacted]

[redacted]

[redacted]

5.5. APPENDIX

This appendix contains proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390. This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

5.5.1. List of References

This section provides a list of the documents that are referred to within Section 5 – “Shielding Evaluation”. The detailed list of the comprehensive SAR references can be found in Section 0 – “Introduction”.

Some of the references listed below might contain proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390: when it is the case, the reference is then clearly identified "(PROPRIETARY)". This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

Ref. 57 U.S. Nuclear Regulatory Commission, 10 CFR Part 71 – Packaging and Transportation of Radioactive Material

Ref. 58 Robatel Industries, “RT-200 Transportation Package without content”, Assembly Drawing, RT-200 PC 001, Rev. D (PROPRIETARY)

Ref. 59 Robatel Industries, “Shielding evaluation of the RT-200 cask loaded with its content no.2”, Technical Note, RT-200 NTE 5002, Rev. A (PROPRIETARY)

Ref. 60 Robatel Industries, “Shielding evaluation of the RT-200 cask loaded with neutron source”, Technical Note, RT-200 NTE 5013, Rev. A (PROPRIETARY)

Ref. 61 McConn, Gesh, Pagh, Rucker, Williams, “Compendium of Material Composition Data for Radiation Transport Modeling”, PNNL-15870 Rev-1, Pacific Northwest National Laboratory, March 2011.

Ref. 62 Werner, et al., “MCNP® User’s Manual, Code Version 6.2”, LA-UR-17-29981 Rev-0, Los Alamos National Laboratory, October 2017

Ref. 63 Conlin, “Listing of Available ACE Data Tables”, LA-UR-17-20709, Los Alamos National Laboratory, January 2017

Ref. 64 ANSI/ANS 6.1.1-1977, “Neutron and Gamma Flux-To-Dose Conversion Factors”

Ref. 65 Cember, Johnson, “Introduction to Health Physics”, 4th Edition

Ref. 66 CN-103622-501, “Calculation package for RT-200 gamma and neutron shielding analysis” (PROPRIETARY)

5.5.2. Cobalt-60 Equivalence

In order to allow gamma emitting nuclides that are not Co-60 in the cask for transportation, energy dependent maximum activities were calculated. The purpose of these activities is to ensure that, regardless of the payload, the dose rates will not exceed the regulatory limits.

The maximum activities are determined by first generating the dose rate response (response function) for various line energies. The dose rate is tallied at 2 m from the side of the package in a band at the same axial location as the maximum 2 m side dose rate reported in Table 5.1-1. The source configuration is the same as the homogenized case, described in section 5.3.1.1.2 ,because this configuration results in the limiting 2 m dose rate. The dose rate as a function of line energy is reported in Table 5.5-1.

[redacted]

Table 5.5-1 Response functions and activity limits by energy for RT-200 (Content No. 2)

[redacted]

5.5.3. Flux-to-Dose Rate Conversion Factors

Table 5.5-2 ANSI/ANS 6.1.1-1977 – Gamma Flux-to-Dose Conversion Factors

Photons Energies (MeV)	Conversion factors (rem/h)/ (photon/cm²/s)	Photons Energies (MeV)	Conversion factors (rem/h)/ (photon/cm²/s)
0.01	3.96E-06	1.40	2.51E-06
0.03	5.82E-07	1.80	2.99E-06
0.05	2.90E-07	2.20	3.42E-06
0.07	2.58E-07	2.60	3.82E-06
0.10	2.83E-07	2.80	4.01E-06
0.15	3.79E-07	3.25	4.41E-06
0.20	5.01E-07	3.75	4.83E-06
0.25	6.31E-07	4.25	5.23E-06
0.30	7.59E-07	4.75	5.60E-06
0.35	8.78E-07	5.00	5.80E-06
0.40	9.85E-07	5.25	6.01E-06
0.45	1.08E-06	5.75	6.37E-06
0.50	1.17E-06	6.25	6.74E-06
0.55	1.27E-06	6.75	7.11E-06
0.60	1.36E-06	7.50	7.66E-06
0.65	1.44E-06	9.00	8.77E-06
0.70	1.52E-06	11.0	1.03E-05
0.80	1.68E-06	13.0	1.18E-05
1.00	1.98E-06	15.0	1.33E-05

Table 5.5-3 ANSI/ANS 6.1.1-1977 – Neutron Flux-to-Dose Conversion Factors

Photons Energies (MeV)	Conversion factors (rem/h)/ (neutron/cm²/s)	Photons Energies (MeV)	Conversion factors (rem/h)/ (neutron/cm²/s)
2.50E-08	3.67E-06	5.00E-01	7.59E-06
1.00E-07	3.67E-07	1	1.32E-04
1.00E-06	4.46E-06	2.5	1.25E-04
1.00E-05	4.54E-06	5	1.56E-04
1.00E-04	4.18E-06	7	1.47E-04
1.00E-03	3.76E-06	10	1.47E-04
1.00E-02	3.56E-06	14	2.08E-04
1.00E-01	2.17E-05	20	2.27E-04

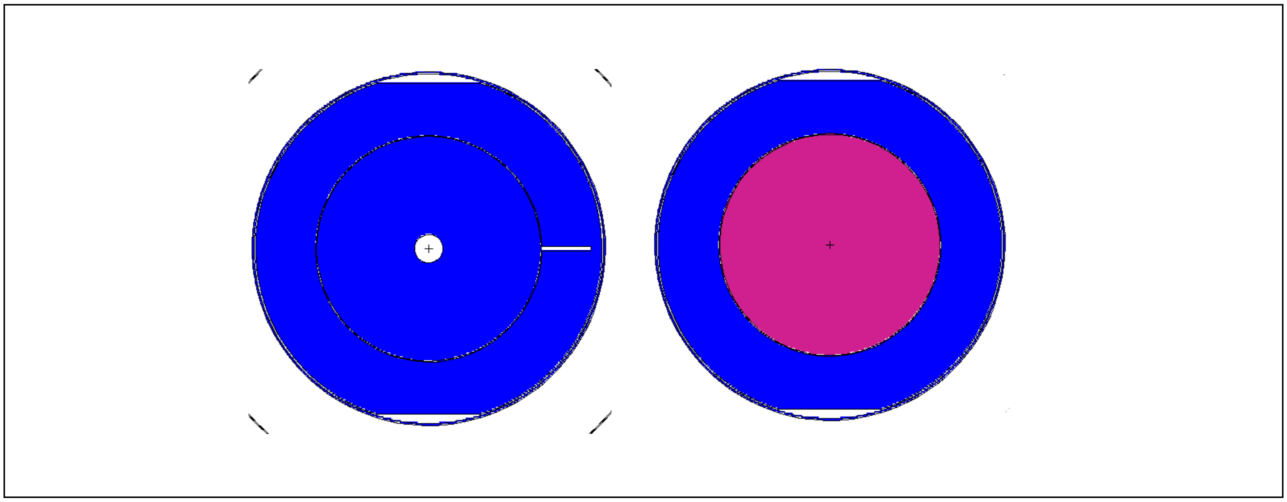
5.5.4. Model Illustrations

5.5.4.1. NCT – Content No. 2

Figure 5.5-1: Overview of RT-200 Content No. 2 model for NCT : axial

[redacted]

Figure 5.5-2: Overview of RT-200 Content No. 2 model for NCT: radial



5.5.4.2. HAC – Content No. 2

Figure 5.5-3: Overview of RT-200 Content No. 2 model – HAC case 1

[redacted]

Figure 5.5-4: Overview of RT-200 Content No. 2 model – HAC case 2

[redacted]

5.5.5. Tallies Illustrations

Figure 5.5-5 : RT-200 Model : Tallies illustrations

[redacted]

5.5.6. Dose Rate Results Visualization

For Content No. 2, calculations have been done with a standardized source of 1 TBq, as described in section 5.4.4.1.

Therefore, the resulting dose rates shown in Figure 5.5-6 are not representative of the real dose in stake, they are only showing the dose rate profile surrounding the cask.

Color scale range used for dose rates visualizations (Rem/h):

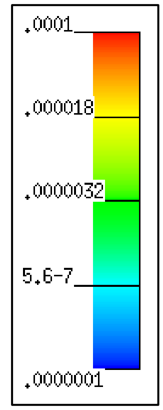


Figure 5.5-6 : Content No. 2 – RT-200 MCNP® Mesh Tally: NCT Dose Rates (Rem/h) – Longitudinal X-Sections

[redacted]

5.5.7. MCNP® Models: Material Composition and Densities

Table 5.5-4 – MCNP® Models: Standard Material Compositions

[redacted]

Table 5.5-5 – MCNP® Models: Material densities

[redacted]

Figure 5.5-7 – RT-200 MCNP® Model: Material Densities

[redacted]

6. CRITICALITY (NOT APPLICABLE)

This Section is NOT APPLICABLE. The RT-200 is not designed to transport fissile material subject to the requirements of 10 CFR 71 Sections 71.55 or 71.59. Therefore, no criticality evaluation is necessary for the SAR of the RT-200.

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7. PACKAGE OPERATIONS

The loading and unloading operations for the RT-200 are described in this chapter for two shipping configurations. Configuration No. 1 describes the configuration of the RT-200 to ship Content No. 1 – Storage Container Content as described in Section 1.2.2.1. Configuration No. 2 describes the configuration of the RT-200 to ship Content No. 2 – General Content as described in Section 1.2.2.2. The fundamental steps needed to ensure that the RT-200 is properly prepared for transport and ensure compliance with the other sections of this report are contained herein. The operating controls and procedures presented in this chapter meet the requirements of 10 CFR Part 71.

Detailed operational procedures used to operate the RT-200 shall meet or exceed the instructions based on this chapter of the report and shall maintain as low as reasonably achievable (ALARA) occupational radiation exposures as required by the "Standards for Protection Against Radiation" in 10 CFR 20.1101(b).

Table of Content

7.1. PACKAGE LOADING

This section describes loading-related preparations, tests, and inspections of the package, including the inspections made before loading the package to ensure that the package is not damaged, and radiation and surface contamination levels are within allowable limits of the regulations.

7.1.1. Preparation for Loading

The following prerequisites shall be completed prior to loading operations:

- The package content data is reviewed to ensure the contents meet the Certificate of Compliance (CoC). When shipping Content No. 1 – Storage Container Content, consult Appendix 7.6.1 which provides guidance for ensuring that contents will meet the Certificate of Compliance dose rate requirements.
- The following conditions must be met for safe handling of the RT-200:
    - All operating instructions/procedures outlined in the Safety Analysis Report (SAR) must be followed.
    - RT-200 shall only be lifted by the top lifting trunnions using a qualified lifting beam or by approved rigging equipment.
    - RT-200 shall not be placed in an upside-down position at any time.
    - RT-200 cask body shall not be handled while tied down to the transport.
- Handle the lid, drain and vent port cover plates, cavity surfaces, bolts, and O-rings as potentially contaminated.
- Inspect all bolts, hole threads, or O-rings, for damage, defects, or signs of deterioration at an appropriate time throughout the steps outlined in this section. Replace with components meeting the specifications in the RT-200 Bill of Material (Chapter 1, Section 1.3.3).
- Maintenance leakage rate testing shall be performed in accordance with Section 8.2.2.1 prior to returning a package to service following maintenance, repair (such as a weld repair), or replacement of components of a containment boundary.

7.1.1.1. Impact Limiter Removal

The front and rear impact limiters are attached via identical hardware, and each must be removed by following the steps in this section.

1. Attach appropriate lifting equipment to the impact limiters.
2. Remove the security seal from the top bolt locking plate.
3. Remove the four (4) bolts (Modified Socket Head Cap Screw, M16x30) in the center of the bolt locking plates and the four (4) bolt locking plates.
4. Remove the eight (8) bolts (Socket Head Cap Screw, M42x110) and washers securing the impact limiter to the cask.
5. Remove the impact limiter and place it on a clean flat surface to prevent damage. The impact limiter should be placed on the integrated feet.
6. Inspect the impact limiters for any signs of damage and remediate as appropriate. Inspect the bolts and rubber spacer on the inside of each impact limiter and replace if damaged in accordance with the RT-200 Bill of Material (Chapter 1, Section 1.3.3).

7.1.1.2. Cask Lifting

The cask is designed to meet critical load requirements in accordance with ANSI N14.6-1993 when lifted from the two (2) bolted lifting trunnions at the top of the cask.

1. Perform a visual inspection to determine if any component has visual external damage that would prevent safe handling and performance of the package. Any damaged/out-of-specification components are repaired or replaced.
2. Remove the hold-down restraints attaching the cask to the transport.
3. Attach a qualified lifting beam and crane to the two (2) bolted lifting trunnions or attach other approved rigging equipment.
4. Lift to orient the cask into the vertical position. Lift the cask up and away from the transport.
5. Lower the cask and slowly place it in a pre-approved location that is clean, flat, level, and secure, and prevents scratching or damage to the cask.

7.1.1.3. Drain and Vent Port Cover Plate Removal

NOTE:

- Before attempting to open the lid, balancing the internal and external pressure will assist with removal of the lid.
- Each cover plate weighs about 9.7 kg (21.4 lbs)
- The drain and vent port cover plates must be set down with caution to prevent scratching or damage.

1. With appropriate tools, loosen and remove four (4) of the six (6) bolts which secure the cover plate to the cask body in a star pattern. Loosen the remaining two (2) bolts.
2. Manually install and hand tighten two (2) of the removed bolts into the two threaded holes specially designed to assist with pulling off the cover plate.
3. Fully remove the remaining two (2) of the six (6) bolts fastening the cover plate to the cask body.
4. Remove the cover plate using the threaded bolts.
5. Vent the cask cavity by connecting the quick-disconnect valve in the vent port to an approved ventilation control system.
6. Inspect the cover plate for any signs of damage and rectify as appropriate.

Repeat steps 1., 2., 3., and 4. above to remove the drain port cover plate.

7.1.1.4. Cask Lid Removal

This section describes the procedure for removing the cask lid. Section 7.1.1.7 describes an acceptable alternative method for preparing the cask for submergence in lieu of this section.

NOTE:

- The lid shall be handled and stored with care in order to prevent scratching or damage.

1. First loosen, then remove all of the bolts (30 Socket Head Cap Screws, M42x140) and washers securing the lid to the cask body in a star pattern.

2. Install four (4) lifting rings (M42) into every other bolt hole that is used for affixing the impact limiters. Attach appropriate lifting equipment.
3. Remove the lid using appropriate lifting equipment.
4. Place the lid on a clean flat surface with care to prevent scratching or damage to the O-rings or the cask mating surfaces.
5. Inspect the lid for any signs of damage and rectify as appropriate.

7.1.1.5. Configuration No. 1 – Basket Installation

This section is only necessary for initial installation of the dedicated basket (Basket No. 1), or if the dedicated basket is not present prior to shipment of Content No. 1. The following steps may occur at any point in the loading sequence prior to loading the disposable inserts at the direction of the cask supervisor.

NOTE:

- The basket shall only be maneuvered when empty.
- Removal of any material from inside the cask is performed under the supervision of qualified health physics personnel, and in accordance with health & safety requirements.
- The basket has no specific clocking orientation required for installation.

1. Visually verify that the basket and the interior of the cask are undamaged, free of debris, and freestanding water is removed.
2. Install three lifting rings (M42) into the dedicated bolt holes at the top of the basket and tighten to the manufacturer required torque. Attach approved lifting equipment.
3. Lift and lower the basket into the cask cavity with care to prevent binding and potential scratching of the interfacing surfaces.
4. Remove the three lifting rings and properly store.

7.1.1.6. Configuration No. 1 – Disposable Insert Installation

This section is only necessary for initial installation of the disposable inserts (Disposable Insert No. 1), or if the disposable inserts are not present prior to shipment of Content No. 1. The following steps may occur at any point in the loading sequence prior to loading the storage containers at the direction of the cask supervisor.

1. Visually verify that accessible areas of the disposable insert are undamaged and free of debris.
2. Attach approved lifting equipment to the lifting lug located at the top of the disposable insert.
3. Lift and lower the disposable insert into the basket with care to prevent binding and potential scratching of the interfacing surfaces.

7.1.1.7. Cask Pre-fill with Water

This section describes an acceptable alternative to fully removing the cask lid as described in Section 7.1.1.4 prior to submergence of the cask.

1. First loosen in one pass, then remove the cask lid bolts (Socket Head Cap Screws, M42x140) and washers in a star pattern. Any number of bolts may remain installed to maintain the lid as appropriate.
2. Install appropriate lid lifting equipment
3. Connect an approved ventilation control system to the vent port quick-disconnect valve as necessary.
4. Connect the water supply line to the drain port and fill the cask with the appropriate volume of water.

7.1.2. Loading of Contents

Follow Section 7.1.2.1 for Content No. 1 loading procedures or follow Section 7.1.2.2 for Content No. 2 loading procedures.

7.1.2.1. Content No. 1 – Storage Container Content Loading

The following steps provide the process necessary to load the RT-200 that are specific to Configuration No. 1, which is used to ship Content No. 1 as defined in Section 1.2.2.1 of Chapter 1. At the direction of the cask supervisor, the steps in Section 7.1.1.5 to install the basket and the steps in Section 7.1.1.6 to install the disposable insert may be performed after the cask has been lowered into the water.

NOTE:

- Cleanliness of the sealing surface will have a direct effect on leak testing results.

1. Radioactively contaminated liquids may be pumped out or removed using absorbent material. Removal of any material from inside the cask is performed under the supervision of qualified health physics personnel, and in accordance with health & safety requirements.
2. Attach appropriate lifting equipment such as a qualified lifting beam and crane to the two (2) bolted lifting trunnions and appropriate lid lifting equipment if the cask lid is present. Lift the cask and if desired, install a bottom protective cover.
3. If loading the cask underwater, slowly lower the cask into the water to prevent inadvertent movement. Place the cask in the designated loading area.
4. Disengage the lifting beam from the trunnions and slowly raise the lifting beam to remove the cask lid if present.
5. Install a seal surface protecting ring.
6. Load up to three (3) storage containers into the disposable insert with care to prevent binding.
7. Remove the seal surface protecting ring.
8. Inspect the cask lid sealing surface and remediate adverse conditions if necessary.
9. Replace the lid following the steps in Section 7.1.2.3.

7.1.2.2. Content No. 2 – General Content Loading

The following steps provide the process necessary to load the RT-200 that are specific to Configuration No. 2, which is used to ship Content No. 2 as defined in Section 1.2.2.2 of Chapter 1.

NOTE:

- Cleanliness of the sealing surface will have a direct effect on leak testing results.

1. Inspect the interior of the cask to ensure it is clean, free of debris, and freestanding water is removed.
2. Radioactively contaminated liquids may be pumped out or removed using absorbent material. Removal of any material from inside the cask is performed under the supervision of qualified health physics personnel, and in accordance with health & safety requirements.
3. Attach appropriate lifting equipment such as a qualified lifting beam and crane to the two (2) bolted lifting trunnions and appropriate lid lifting equipment if the cask lid is present. Lift the cask and if desired, install a bottom protective cover.
4. If loading the cask underwater, slowly lower the cask into the water to prevent inadvertent movement. Place the cask in the designated loading area.
5. Disengage the lifting beam from the trunnions and slowly raise the lifting beam to remove the cask lid if present.
6. Install a seal surface protecting ring.
7. Load content in a manner to not damage any sealing surfaces or cask interior.
8. Remove the seal surface protecting ring.
9. Inspect the applicable sealing surface and remediate adverse conditions if necessary.
10. Replace the lid following the steps in Section 7.1.2.3.

7.1.2.3. Cask Lid Replacement

NOTE:

- The lid shall be handled and stored with care in order to prevent scratching or damage.
- The steps to prepare the lid for installation may be taken at any appropriate time.

1. Inspect and clean the O-rings and correct any damage, crack, or condition that is noted.
2. Lubricate if necessary the thirty (30) lid bolts (Socket Head Cap Screws, M42x140).
3. Install appropriate lid lifting equipment.
4. Take note of the position of the two (2) locating holes, connect the lifting equipment to a qualified crane, and lift the lid.
5. Lower the lid such that the two (2) locating holes align with the two (2) locating pins installed on the cask.
6. Verify that the lid is fully seated on the cask.
7. If the cask has been loaded underwater, engage a qualified lifting beam to the two (2) bolted lifting trunnions and start to remove the cask from the water.
    a. Once the cask lid is accessible above water, install two cask lid bolts and washers and tighten to 7 N-m $\pm$10% (hand tight).
8. Install the bolts with washers. Tighten the bolts using the “star pattern” method to ensure evenly distributed pressure on the lid and cask body.

    a. Use an initial torque of 400 N-m ± 10%.
    b. Use a final torque of 800 N-m ± 10%.
9. Remove the lifting equipment from the lid.

7.1.2.4. Cask Draining

NOTE:

- Removal of any material from inside the cask should be performed under the supervision of the cask supervisor and qualified health physics personnel, and in accordance with health & safety requirements.
- The cask drains with gravity, so flow will start immediately upon connection of the drainage system.

1. Connect the quick-disconnect valve in the vent port to an approved ventilation control system.
2. Connect the quick-disconnect valve in the drain port to a suitable drainage system.
3. Verify that the appropriate amount of water was removed to ensure the residual water content is in compliance with the requirements from Section 7.5.

7.1.2.5. Drain and Vent Port Cover Plate Replacement

NOTE:

- Each cover plate weighs about 9.7 kg (21.4 lbs)
- The steps to prepare the cover plates for installation may be taken at any appropriate time.

1. Clean and inspect the O-rings and correct any damage, crack, or condition that is noted.
2. Lubricate (if necessary) the six (6) quick-disconnect valve cover plate bolts and hole threads.
3. Install two (2) of the cover plate bolts (Socket Head Cap Screw, M16x60) in the threaded holes in the center of the cover plate. Manually place the cover plate on the cask body. Thread two (2) bolts into the cask body to loosely secure the cover plate. Remove the two (2) bolts threaded into the cover plate.
4. Install the remaining four (4) bolts into the cask body and tighten bolts using a “star pattern” method to ensure consistent pressure on the cover plate and the lid.
    a. Use an initial torque of 7 N-m ± 10% (hand tight) to compress the O-rings.
    b. Use a final torque of 70 N-m ± 10%.

7.1.3. Preparation for Transport

1. Perform Pre-Shipment Leak Testing in accordance with Section 8.2.2.2
2. Lubricate transport saddles, qualified lifting beam hooks as applicable, bottom transport trunnions, and bolted lifting trunnions in accordance with plant operations manuals.
3. Attach a qualified lifting beam and crane to the two (2) bolted lifting trunnions or attach other approved rigging equipment.
4. Lift the cask and position the cask such that the lower transport trunnions are directly above the transport trunnion saddles.

5. Lower the cask such that it rotates in the transport trunnion saddles until the cask is in the horizontal orientation and rests on all four transport trunnions.
6. Fasten the hold-down restraints to attach the cask to the transport.
7. Install the front impact limiter, as identified by the markings, on the top of the cask and rear impact limiter on the bottom of the cask and fasten with the eight (8) bolts (Socket Head Cap Screw M42 x 110) and washers. Tighten bolts using a “star pattern” method.
    a. Use an initial torque of 400 N-m ±10%.
    b. Use a final torque of 800 N-m ±10%.
8. Install the four (4) bolt locking plates with the four (4) respective bolts (Modified Socket Head Cap Screw, M16x30) and install a new security seal on the top bolt locking plate bolt in accordance with RT-200 Bill of Material (Chapter 1, Section 1.3.3).
9. Complete a contamination survey on the external surfaces to confirm that non-fixed (removable) radioactive contamination is within the limits specified in 49 CFR 173.443, as required by 10 CFR 71.87. If contamination is within limits, preparation for transport may be conducted. If contamination exceeds the limits, the RT-200 must be decontaminated until the contamination limits are met.
10. Perform a preliminary gamma radiation measurement to verify that the cask meets NRC requirements.

7.1.3.1. Verification for Transport

The following actions are confirmed prior to shipment of a loaded package.

1. A licensed consignee who expects to receive the package containing materials in excess of Type A quantities specified in 10 CFR 71.4 meets and follows the requirements of 10 CFR 20.1906, as applicable.
2. Before delivery of a package to a carrier for transport, the shipper shall ensure that any special instructions needed to safely open the package have been sent to, or otherwise made available to, the consignee for the consignee’s use in accordance with 10 CFR 20.1906.
3. Trailer placarding and cask labeling meet DOT specifications (49 CFR 172).
4. Provisions of 10 CFR 71.87 are met.
5. Measure the exterior gamma radiation levels in accordance with 10 CFR 71.47 to ensure they do not exceed the following limits:
    - 200 millirem per hour (2 mSv/h) at any point on the vertical planes projected from the outer edges of the trailer, on surface of the impact limiter at the axial center line of the package, and on the lower external surface of the trailer
    - 10 millirem per hour (0.1 mSv/h) at any point 2 meters (6.6 feet) from the vertical planes projected by the outer edges of the trailer (excluding the underside of the trailer)
    - 2 millirem per hour (0.02 mSv/h) in the tractor cab, in accordance with 49 CFR 173.441 and 10 CFR 71.47.
6. No temperature survey is required. The thermal evaluation demonstrates that the temperature requirement of 10 CFR 71.43(g) is met.
7. Security seals are properly installed as required by 10 CFR 71.43(b).
8. Inspect the exterior of the cask and correct any damage prior to shipping a loaded package following appropriate procedures.
9. Ensure that the RT-200 is correctly tied down to the transport.

10. During transport, the carrier shall avoid actions that will unnecessarily delay delivery or unnecessarily result in increased radiation levels or radiation exposures to transport workers or members of the general public.

7.2. Package Unloading

The following sections describe the steps necessary to unload the package. Shipments in excess of Type A quantities as specified in 10 CFR 71.4 shall be received, monitored, and handled by the consignee receiving the package in accordance with the requirement of 10 CFR 20.1906, as applicable. Packages containing greater than Type A quantities may be identified by reviewing the shipping papers.

NOTE:

- The following conditions must be met for safe handling of the RT-200:
    - All operating instructions/procedures outlined in the Safety Analysis Report (SAR) must be followed.
    - RT-200 shall only be lifted by the top lifting trunnions using a qualified lifting beam or by approved rigging equipment.
    - RT-200 shall not be placed in an upside-down position at any time.
    - RT-200 cask body shall not be handled while tied down to the transport.
- Handle the lid, drain and vent port cover plates, cavity surfaces, bolts, and O-rings as potentially contaminated.

7.2.1. Receipt of Package from Carrier

1. Any special instructions provided by the shipper in accordance with 10 CFR 71.89 are reviewed and followed.
2. Perform a visual inspection in accordance with Chapter 8, Section 8.2.3.1 to determine if any component has visual external damage that would prevent safe handling and performance of the package. Any damaged/out-of-specification components are repaired or replaced.
3. Inspect the security seal on the top bolt locking plate on the upper and lower impact limiters. The shipper is notified, and the shipment may be rejected by the consignee if the security seal has been removed or tampered with in any way. At the consignee's discretion, the consignee may proceed to accept the RT-200 contents if the security seal was damaged during shipment.
4. Perform a gamma radiation measurement to verify that the cask meets NRC requirements. If the survey exceeds the limits, the shipper is notified immediately, and the shipper collaborates with the consignee, or the appropriate regulatory authorities and DOT, to resolve the issue.

7.2.2. Removal of Contents

1. Remove the impact limiters in accordance with Section 7.1.1.1.
2. Lift the cask in accordance with Section 7.1.1.2.
3. Remove the vent port cover plate and vent the cask in accordance with Section 7.1.1.3.
4. Remove the cask lid in accordance with Section 7.1.1.4.
5. Use appropriate equipment to remove the contents.

6. Inspect the RT-200 interior for any damage, loose material, or moisture. Remediate the residual water content in the cask in accordance with Section 7.1.2.4 if necessary.
7. Inspect all bolts, hole threads, and O-rings, for damage, defects, or signs of deterioration. Replace them with components meeting the specifications in the RT-200 Bill of Material (Chapter 1, Section 1.3.3).
8. Clean seal surfaces.

7.3. PREPARATION OF EMPTY PACKAGE FOR TRANSPORT

The RT-200 may be transported when empty in accordance with 49 CFR 173.428.

1. Confirm the cavity is empty of materials and freestanding water. The basket and an empty disposable insert may remain.
2. Survey the cask lid, the vent and drain port covers, and the interior of the cask.
3. Decontaminate the cask lid, vent and drain port covers, and the internal cask surfaces if the limits of 49 CFR 173.428(d) are exceeded.
4. Replace and secure the lid in accordance with Section 7.1.2.3.
5. Replace and secure the vent port cover plate in accordance with Section 7.1.2.5.
6. Lubricate transport saddles, qualified lifting beam hooks as applicable, bottom transport trunnions, and bolted lifting trunnions.
7. Attach a qualified lifting beam and crane to the two (2) bolted lifting trunnions or attach other approved rigging equipment.
8. Lift the cask and position the cask such that the lower transport trunnions are directly above the transport trunnion saddles.
9. Lower the cask such that it rotates in the transport trunnion saddles until the cask is in the horizontal orientation and rests on all four transport trunnions.
10. Fasten the hold-down restraints to attach the cask to the transport.
11. Inspect the rubber spacer on the inside of each impact limiter and replace it if damaged in accordance with RT-200 Bill of Material (Chapter 1, Section 1.3.3).
12. Install the front impact limiter, as identified by the markings, on the top of the cask and rear impact limiter on the bottom of the cask and fasten with the eight (8) bolts (Socket Head Cap Screw M42 x 110) and washers. Tighten bolts using a “star pattern” method.
    a. Use an initial torque of 400 N-m +10%.
    b. Use a final torque of 800 N-m +10%.
13. Install the four (4) bolt locking plates with the four (4) respective bolts (Modified Socket Head Cap Screw, M16x30) and install a new security seal on the top locking plate bolt in accordance with RT-200 Bill of Material (Chapter 1, Section 1.3.3).
14. Inspect the exterior of the cask for and correct any damage prior to shipping a loaded package following appropriate procedures.
15. Cask labeling meets DOT specifications as specified in 49 CFR 172.428(d).
16. Verify that all requirements in 49 CFR 173.428 have been met.

7.4. OTHER OPERATIONS

There are no other operations identified for handling of the RT-200.

7.5. HYDROGEN BUILDUP IN RT-200 TRANSPORT CASK

The RT-200 is designed for a maximum decay heat of 1200 W. The rate of hydrogen gas generation must also be considered when evaluating the heat load. The method for calculating the hydrogen gas generation is described in Section 4.5.3 An analytical model is described and an example calculation using the analytical model is detailed in the following sections.

The analysis concerns the gas generation of any residual water in the containment vessel. Other hydrogenous materials are not allowed inside the cask's cavity. Therefore, if the content loaded inside the cavity is dry, no hydrogen gas will be generated, and the shipping period is thus not limited.

7.5.1. Hydrogen Gas Generation – Analytical Model

The equations given in Section 4.5.3 can be used to determine the maximum shipping time and the maximum allowable decay heat. Equations are given below:

Determination of maximum shipping time based on a known decay heat:

$$2 \cdot t_{max} = \frac{\frac{P_0\left(0.9 * \left(V_{cavity} - V_{content}\right)\right)}{R_g T_0} \cdot X_H}{\frac{D_H}{100} \frac{G_{eff,T}}{A_N} \cdot (\alpha - X_H)}$$

With :

- X_H = 0.05 according to Section 4.4.1.1 of NUREG/CR-6673,
- D_H = decay heat that is absorbed by the radiolytic materials [eV/s],
- α = 1, see Section 4.4.2,
- $A_N = 6.022 \cdot 10^{23}$ molecules/gmol,
- $R_g = 82.05$ $cm^3 \cdot atm/gmol \cdot K$,
- P_0 = pressure when the container is sealed [atm],
- T_0 = temperature when the container is sealed [K],
- $V_{content}$ = volume occupied by the content,
- V_{cavity} = volume of the containment vessel = $4.34 \cdot 10^6$ cm^3,
- t_{max} = maximum allowable shipping time [seconds]
- $G_{eff,T}$ = total radiolytic effective G value [molecules/100eV], detailed below,

$$G_{eff,T} = \left(\frac{1}{\frac{m}{0.1 \cdot \left(V_{cavity} - V_{content}\right) \cdot \rho_{water}} + 1}\right) \cdot \left(\lambda_\alpha \cdot G_{W,\alpha} + \lambda_{\beta/\gamma} \cdot G_{W,\beta/\gamma}\right)$$

With:

- m = payload mass [kg]
- ρ_{water} = density of water [g/cm^3]
- λ_α is the fraction of the decay energy due to alpha decay

- $\lambda_{\beta/\gamma}$ is the fraction of the decay energy due to beta and gamma decay
- $G_{W,\beta/\gamma}$= G value for water (liquid phase, beta/gamma radiation) = 0.45 Molecules/100 eV
- $G_{W,\alpha}$= G value for water (liquid phase, alpha radiation) = 1.60 Molecules/100 eV

Use of equations above are valid and shipments are allowed only when the conditions listed hereafter are met:

- Waste consists of solid irradiated and contaminated non-fuel-bearing metallic hardware.
- If the package is loaded underwater and drained, no more than 10% residual water by mass will remain in the packaging (dewatering criterion is 10%).
- Except from water, no other hydrogenous materials are loaded in the RT-200.

Use the following procedure to confirm the decay heat of the cask contents meets the requirements of NUREG/CR-6673:

- Determine the values of the variables P_0, T_0, m, ρ, $V_{content}$. Initial pressure (P_0) and initial temperature (T_0) may be measured by the user at the time of loading. The payload mass of the content and the mean density are known. The volume occupied by the content ($V_{content}$) (including possible shoring and secondary containers) is deducted from these values.
- Determine the values of the variables λ_{α}, $\lambda_{\beta/\gamma}$ and $G_{eff,T}$. λ fractions must be justified by the user based on waste characterization (adjusted for the appropriate alpha/gamma radiation distribution).
- Take the decay heat of the cask contents (D_H) and solve the first equation for the maximum allowable shipping time (t_{max}). Confirm the actual shipment time (t) will be less than the maximum allowable shipping time (t_{max}).

7.5.2. Hydrogen Gas Generation – Analytical Model Example

An example calculation using the analytical model developed in Section 7.5.1 is shown below. The following variables and constants are known:

- A_N = $6.022 \cdot 10^{23}$ molecules/gmol,
- R_g = 82.05 $cm^3 \cdot atm/gmol \cdot K$,
- $G_{W,\beta/\gamma}$ = 0.45 Molecules/100 eV
- $G_{W,\alpha}$ = 1.60 Molecules/100 eV
- ρ_{water} = 1 g/cm^3
- α = 1
- V_{cavity} = $4.34 \cdot 10^6$ cm^3

In this example, the user has input the following parameters:

- On initial conditions
  - P_0 = 1 atm
  - T_0 = 311 K
- On the content:

- $m =$ 8,400 kg
- $\rho =$ 7.85 g/cm^3
- $\lambda_\alpha =$ 0.01
- $\lambda_{\beta/\gamma} =$ 0.99
- $D_H =$ 1200 W = $7.49 \cdot 10^{21}$ eV/s

- On regulatory requirement:
  - $X_H =$ 0.05

$$G_{eff,T} = \left(\frac{1}{\frac{8400 \cdot 10^3}{0.1 \cdot \left(4.34 \cdot 10^6 - \frac{8400 \cdot 10^3}{7.85}\right) \cdot 1} + 1} \right) \cdot (0.01 \cdot 1.60 + 0.99 \cdot 0.45)$$

$G_{eff,T}$ = 0.017 molecules/100eV

Then, the maximum shipment time (t_{max}), may be calculated (considering a security factor of 2 as required by NUREG/CR-6673):

$$t_{max} = \frac{1}{2} \left(\frac{\frac{1 * 0.9 \cdot \left(4.34 \cdot 10^6 - \frac{8400 \cdot 10^3}{7.85}\right)}{82.05 * 311} \cdot 0.05}{\frac{7.49 \cdot 10^{21}}{100} \frac{0.017}{6.022 \cdot 10^{23}} \cdot (1 - 0.05)} \right)$$

$$t_{max} = 16\ days$$

Therefore, it shows that, in the initial conditions presented as an example, hydrogen gas generated in the package during a period of 16 days will not exceed 5 % by volume (with a security factor of 2) of the free gas volume in the containment system of the package.

Therefore, due to radiolysis, in this example, the shipping period would be limited to 16 days.

7.5.3. Hydrogen Gas Generation – Alternative Calculation

Alternatively, the user can follow another applicable method in accordance with NUREG/CR-6673 to determine the shipping time to reach the required hydrogen concentration of 5%. The shipping time must be defined as ½ the time to reach the 5% hydrogen concentration per the requirement in NUREG/CR-6673.

7.6. APPENDIX

This appendix contains proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390. This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

7.6.1. Content No.1: Radiation Level Guidelines

This non-mandatory guideline is provided to give the user assurance that the storage container dose rate measurements taken underwater for each individual storage container will lead to acceptable external dose rates taken on the exterior of the RT-200 in accordance with 10 CFR 71.47. However, compliance with these guidelines does not exempt the user from verifying the requirements stated in 7.1.3.1 for exterior gamma radiation levels. Alternate internal procedures may be developed to otherwise meet the external radiation standards for all packages outlined in 10 CFR 71.47.

The maximum total activity of Content No. 1 (including three storage containers) is limited to 30,000 Ci (1.11E+15 Bq) and 3,000 A2 in accordance with Type B quantities defined in 10 CFR 71.4. Co-60 is assumed to be the principal gamma emitter nuclide within the storage container's (SC) content. The RT-200 shielding has been analyzed and shown to provide adequate radiological protection with margin for three SCs each with maximum radiation levels shown in Table 7.6-1. The maximum radiation levels for each SC correspond to the dose rate measurements taken underwater and:

- at 15 cm (6 in.) from both the SC top and bottom surfaces (axial)
- at either 15 or 30 cm (6 or 12 in. respectively) from the SC sides (lateral)*

Table 7.6-1 Limits on Radiation Levels around a SC (underwater)

Location *(elevation reference: 0 = SC's bottom)*		**Maximum Radiation Levels**				
SC's Top Extremity (axial):		***@ 15 cm (6"):***				
Top + 15 cm	*(+0.5')*	10 Sv/h	*(1000 rem/h)*			
SC's Sides (lateral):		***@ 15 cm (6"):***			***@ 30 cm (12"):***	
442 cm	*(14.5')*	18 Sv/h	*(1800 rem/h)*		9 Sv/h	*(900 rem/h)*
411 cm	*(13.5')*	32 Sv/h	*(3200 rem/h)*		16 Sv/h	*(1600 rem/h)*
351 cm	*(11.5')*	17 Sv/h	*(1700 rem/h)*		4 Sv/h	*(400 rem/h)*
289 cm	*(9.5')*	17 Sv/h	*(1700 rem/h)*	*or**	4 Sv/h	*(400 rem/h)*
229 cm	*(7.5')*	17 Sv/h	*(1700 rem/h)*		4 Sv/h	*(400 rem/h)*
168 cm	*(5.5')*	17 Sv/h	*(1700 rem/h)*		4 Sv/h	*(400 rem/h)*
107 cm	*(3.5')*	17 Sv/h	*(1700 rem/h)*		4 Sv/h	*(400 rem/h)*
10 cm	*(0.3')*	56 Sv/h	*(5600 rem/h)*		28 Sv/h	*(2800 rem/h)*
SC's Bottom Extremity (axial):		***@ 15 cm (6"):***				
Bottom -15 cm	*(-0.5')*	20 Sv/h	*(2000 rem/h)*			

* *Regarding the SC's sides, either the 15 or the 30 cm limits can be used as a choice to verify that an SC adheres to the guidelines set in Table 7.6-1: if either of these two measurements is met, the SC is acceptable in accordance with these guidelines.*

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

An Assessment Test Program is implemented to meet the requirements of 10 CFR Part 71 [Ref. 67], Subpart G to evaluate initial acceptance of the RT-200. The RT-200 Package Maintenance Program ensures the RT-200 cask meets its Certificate of Compliance requirements throughout the package service life. Both the acceptance tests and maintenance programs are conducted in accordance with the RT Quality Assurance Program [Ref. 76].

Table of Content

8.1. ACCEPTANCE TESTS

Prior to the first use of the RT-200, the following tests and evaluations will be performed. Once the design has been approved by the Commission and all fabrication requirements and tests outlined in this SAR have been met, the cask will be conspicuously marked with the model number, serial number, gross weight, and the package identification number assigned by the NRC.

8.1.1. Visual Inspections and Measurements

Throughout the fabrication process, confirmation by visual inspection and measurement are required to verify that the RT-200 packaging dimensionally conforms to the drawings provided in Chapter 1, Appendix 1.3.4. In addition, the packaging is to be visually inspected for any adverse conditions in materials or fabrication such as cracks, pinholes, uncontrolled voids, or other defects that would prevent the package from being assembled or operated in accordance with requirements outlined in Chapter 7 or tested in accordance with the requirements of Chapter 8. Visual and non-destructive examinations shall be performed by ASNT or COFREND certified inspectors. Any nonconforming condition shall be evaluated and reworked or replaced as applicable.

8.1.2. Weld Examinations

Containment boundary welds are identified in the drawing provided in Chapter 1, Appendix 1.3.7. The following welds on this drawing are classified as containment boundary welds: [redacted] These welds are required to be inspected and meet the acceptance requirements of ASME Code, Section III, Division I, Subsection NCD, Article NCD-5000 [Ref. 68].

Each containment weld on the RT-200 is performed in accordance with ASME Code, Section III, Division I, Subsection NCD – Class 3. All safety-related welds other than containment welds are performed in accordance with ASME Code, Section III, Division I, Subsection NF. Radiographic testing, dye penetrant testing, and/or visual testing are performed in accordance with applicable ASME standards. The containment boundary welds are also inspected by radiographic examination. Non-destructive examination shall be performed by ASNT or COFREND certified inspectors.

8.1.3. Structural and Pressure Tests

The bolted lifting trunnions shall be subjected to a test load equal to three times the weight of the maximum service load for at least 10 minutes in accordance with ANSI N14.6 Section 7.3.1(a) [Ref. 70]. The total test load on the trunnions pair shall be 2,128 kN[4] (i.e. 1,064 kN per trunnion).

A pressure test of the containment system is performed as required by 10 CFR 71.85 [Ref. 67]. As described in Chapter 3, Section 3.1.4, Maximum Normal Operating Pressure for the RT-200 cavity is 98.675 kPa (gauge). Per 10 CFR 71.85(b) [Ref. 67], the containment system shall be tested at an internal pressure at least 50% higher than the actual maximum normal operating pressure.

[4] This test load corresponds to 3 times the maximum weight of the loaded package, without impact limiters and filled with water (72,300 kg).

150 kPa is used conservatively for the hydrostatic test pressure and is held for a minimum of 10 minutes. Afterward, the cask lid is examined for leakage.

If a leak is detected, except from temporary connections, leaks are remedied, and the test and inspection are repeated. After depressurization and draining, the cask cavity and seal areas are visually inspected for cracks and deformation. Any cracks or deformation are remedied, and the test and inspection are repeated.

8.1.4. Leakage Tests

Detailed leakage test procedures shall at a minimum meet the requirements below and shall be approved by ASNT NDT or COFREND Level III leak testing certified personnel. The use of COFREND certified personnel instead of ASNT certified personnel is accepted for leakage testing for the RT-200.

The test method, leak test sensitivity, and test acceptance criteria for all applicable equipment to be tested for acceptance are located in Table 8.3.2-1. Any condition which results in leakage in excess of the maximum allowable leak rate is corrected and re-tested.

The entire containment boundary of the RT-200 will be helium leak tested during fabrication to verify adequate containment welds and features. [redacted]

For each helium test, the duration must be calculated by test personnel. The test duration is a function of the system response time and the helium permeation time.

In accordance with Ref. 74, Ref. 75 and Ref. 76, the system response time is defined as the elapsed time for a test system to yield a stable leakage rate signal following a change in tracer gas leakage rate. The system response time should be determined by use of a calibrated leak or by allowing a small amount of the tracer into the loosened fitting or valve. Then the envelope should be filled with the tracer gas and the response of the detector should be monitored. The partial pressure of the tracer gas in the envelope should be at least 10% of the total gas pressure and must be known.

The containment system includes elastomeric materials and therefore permeation can be a problem when a leakage test procedure is being used to demonstrate that the system is leaktight. The degree of permeation is affected by seal material, seal surface area, time, and temperature. The recommendations of ANSI N14.5-2014 should be considered to eliminate permeability as a factor in leakage rate measurements.

The test duration should be such that:

$$System\ Response\ Time\ < Test\ Duration\ < Helium\ Permeation\ Time$$

This will ensure that a stable leakage rate signal is established and will ensure that the leakage tests are completed before permeation reaches a significant level.

8.1.5. Component and Material Tests

The components and materials procured for the RT-200 are selected to assure that there will be no significant chemical, galvanic, or other reaction among the packaging components, among package contents, or between the packaging components and the package contents, including possible reaction resulting from inleakage of water, to the maximum credible extent (10 CFR 71.43(d), [Ref. 67]).

8.1.5.1. Foam

[redacted]

8.1.5.2. Elastomeric O-Ring

[redacted]

[redacted]

8.1.5.3. Ceramic Paper

[redacted]

Table 8.1.5-1 Critical Characteristics of Ceramic Paper

[redacted]

8.1.5.4. Fusible Plugs

[redacted]

8.1.5.5. Steel Materials

All steel materials used for the RT-200 shells, forgings, lid, cover plates, trunnions, and bolts shall conform to the respective ASME or ISO standard selected for each component.

8.1.6. Shielding Tests

The RT-200 is designed to provide sufficient shielding to meet or exceed NRC and DOT requirements for a Type B(U) package. Specifically, the RT-200 design includes gamma radiation shielding to meet 10 CFR Part 71.47 [Ref. 67] during both NCT and HAC.

The lead thickness, and thus the shielding integrity of the RT-200, is verified using ultrasonic scanning dimensional surveys in accordance with NUREG/CR-3854 to ensure a minimum thickness of [redacted] The shielding is considered acceptable if the measurements taken indicate that no lead layer is less than the minimum specified thickness and no unacceptable defect is detected. Any results not meeting this requirement are remedied, and the test and inspection are repeated.

8.1.7. Thermal Tests

No thermal acceptance testing is required for the RT-200. Refer to the thermal evaluation of the RT-200 described in Chapter 3, Section 3.3, Thermal Evaluation under Normal Conditions of Transport and 3.4 Thermal Evaluation under HAC of the SAR.

8.1.8. Miscellaneous Tests

No operating tests beyond the tests described in the previous sections are required on the RT-200 package for acceptance.

8.2. MAINTENANCE PROGRAM

The RT-200 is subjected to routine inspection and periodic maintenance to ensure its compliance with this SAR and standards required by the NRC. Defective items are replaced or remedied and tested as appropriate. If the RT-200 does not comply with the specifications and verifications of the SAR, it is taken out of service until the corrective action(s) have been completed. All corrective actions are reported to RT, the NRC, and approved RT-200 Users.

8.2.1. Structural and Pressure Tests

No routine or periodic pressure testing will be performed on the RT-200 transportation cask.

The bolted lifting trunnions shall be tested annually to verify continuing compliance and following any major modification or repair in accordance with ANSI N14.6 Section 7.3.1(a) [Ref. 70] requirements (principles related to the acceptance test described in Section 8.1.3 apply).

8.2.2. Leakage Tests

All procedures shall meet the requirements for leakage testing below and shall be approved by ASNT NDT or COFREND Level III certified personnel in leakage testing. Leakage rate testing shall be performed by personnel that are qualified and certified in accordance with the requirements of SNT-TC-1A-2006 or COFREND equivalent.

8.2.2.1. Periodic and Maintenance Leak Test

Leak testing of the RT-200 must be performed after completion of annual inspection and after maintenance or repair of the containment boundary components. This includes after replacement of containment seals (cask lid, vent port, and drain port cover plates). All requirements for leakage test procedures, repair and replacement, and testing personnel qualification and certification shall be in accordance with ANSI N14.5 [Ref. 71] or ISO 12807 [Ref. 73], in accordance with NUREG 2216 provisions [Ref. 75].

These tests must be carried out and interpreted by ASNT-SNT-TC-1A or COFREND II qualified personnel in accordance with NF EN ISO 9712 [Ref. 72].

The test method, leak test sensitivity, and test acceptance criteria for all applicable equipment to be tested annually or after maintenance or repair are located in Table 8.3.2-1. Any condition which results in leakage in excess of the maximum allowable leak rate is corrected and re-tested prior to returning the cask to service.

8.2.2.2. Pre-Shipment Leak Test

A leak test of the RT-200 is required before each shipment of Type B material to verify proper integrity of the containment system. Test equipment shall be calibrated and traceable to an appropriate standard.

The test method, leak test sensitivity, and test acceptance criteria for all applicable equipment to be tested prior to each shipment of Type B material are located in Table 8.3.2-1. Any condition which results in leakage in excess of the maximum allowable leak rate is corrected and re-tested prior to shipment.

8.2.3. Components and Material Tests

8.2.3.1. Routine Component Inspection

Maintenance during normal use is performed to ensure that the RT-200 continues to meet design specifications and functions. The following components shall be visually inspected at an appropriate time throughout the operational procedures outlined in Chapter 7:

- *Fasteners*: Inspect bolts, nuts, washers, alignment pins, and thread inserts. Clean each component and replace as necessary.
- *Subcomponents*: Inspect the condition of the cask lid, vent port cover plate, drain port cover plate, upper impact limiter, and lower impact limiter.

- *Welds*: Inspect the condition of the transport trunnion welds to verify that no deformation, cracks, or obvious defects are visible.
- *Seals*: Inspect the RT-200 seals and check maintenance records to ensure the seals are within the 12-month replacement period. Inspect the sealing surfaces to ensure the surface is clean and free of damage. If replacement is necessary, perform a leakage rate test after seal replacement.
- *Markings*: Inspect and record the legibility of the RT-200 labeling. Repair if necessary.

8.2.3.2. Annual Component Inspection

Inspections, tests, and maintenance are performed every twelve (12) months of cask service as required in accordance with the SAR and NRC requirements. The following steps are performed to ensure all components are in proper working order:

1. Following procedures in Chapter 7, the RT-200 is disassembled into its components. The exterior surfaces of the cask and its components are visually inspected for damage and the results of the survey are documented. The major components and items to be inspected include the following items:
    - Upper and Lower impact limiters, including fusible plugs
    - Cask lid
    - Vent port and drain port cover plates
    - Vent port and drain port quick-disconnect valves
    - Cask lid, vent port cover plate, and drain port cover plate O-rings
    - Leak test port plugs
    - Cask body, including lifting trunnions and transport trunnions
    - Basket
2. Cask visible exterior surface welds and interior cavity welds are visually inspected for defects.
3. Inspect the condition and readability of the RT-200 markings
4. The cask lid, vent port cover plate, and drain port cover plate sealing surfaces are cleaned.
5. New cask lid, vent port cover plate, and drain port cover plate O-rings are installed according to the recommendation of NUREG-1609 [Ref. 74].
6. Test the bolted lifting trunnions in accordance with Section 8.2.1.
7. The cask lid, vent port cover plate, and drain port cover plate bolts shall be replaced after 500 cycles based on cask operator records. One cycle is defined as when the bolts are installed and fully torqued.

8.2.4. Thermal Tests

No thermal testing is required for the RT-200. Refer to the thermal evaluation of the RT-200 described in Chapter 3, Section 3.3, Thermal Evaluation under Normal Conditions of Transport and 3.4, Thermal Evaluation under HAC of the SAR.

8.2.5. Miscellaneous Tests

Threaded inserts may be used to repair threaded bolt holes. At a minimum, each repaired bolt hole will be tested for proper installation by assembling the joint components where the insert is used and ensuring the bolt can be tightened to the required torque. Refer to Table 1.3-5 of Chapter 1, Appendix 1.3.8 for applicable torque requirements.

If a threaded hole for a lifting component is repaired, a load test shall be performed. The affected component shall be tested at a minimum to 150% of the maximum service load. Each threaded insert shall be visually inspected after testing to ensure that there is no visible damage or deformation to the insert.

8.3. APPENDIX

This appendix contains proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390. This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

8.3.1. List of references

This para provides a list of the documents that are referred to within the section 8 – "Acceptance tests and Maintenance program". A comprehensive summary list of the entire SAR references is provided in Section 0 – "Introduction".

Some of the references listed below might contain proprietary information that Robatel requests be withheld from public disclosure under 10 CFR 2.390: when it is the case, the reference is then clearly identified "(PROPRIETARY)". This request is in accordance with the Robatel Affidavit and as requested in 10 CFR 2.390.

Ref. 67 U.S. Nuclear Regulatory Commission, 10 CFR Part 71 – Packaging and Transportation of Radioactive Material

Ref. 68 ASME Boiler & Pressure Vessel Code 2021 Edition, Section II "Materials" + Section III, Division 1 – Subsections NCD "Class 3 Components" & NF "Class support"

Ref. 69 ASTM D1418-22, "Standard Practice for Rubber and Rubber Latices - Nomenclature", American Society for Testing and Materials

Ref. 70 ANSI N14.6-1993, "American National Standard for Special Lifting Devices for Shipping Containers Weighing 10000 pounds (4500 kg) or More for Nuclear Materials", American National Standards Institute, Inc., 11 West 42nd Street, New York, NY

Ref. 71 ANSI N14.5-2014/2022, "American National Standard for Radioactive Materials, Leakage Tests on Packages for Shipment", American National Standards Institute, Inc., 25 West 43rd Street, New York, NY

Ref. 72 ISO 9712, "Non-destructive testing - Qualification and certification of NDT personnel", International Organization for Standardization, 2021 edition

Ref. 73 ISO 12807, "Safe Transport of Radioactive Materials – Leakage Testing on Packages", International Organization for Standardization, 2018 edition

Ref. 74 NUREG 1609, "Standard Review Plan for Transportation Packages for Radioactive Material", Final Report, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, March 1999

Ref. 75 NUREG 2216, "Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material", Final Report, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, August 2020

Ref. 76 Robatel Technologies, LLC, Quality Assurance Program Description 10 CFR 71 Subpart H for Packaging and Transportation of Radioactive Material, Rev. 4, Dated August 11, 2021, and NRC Approved on March 21, 2012 (PROPRIETARY)

8.3.2. Summary of Leak Test Requirements

The maximum leakage rates are determined using the methods outlined in Chapter 4, Section 4.3. The minimum required sensitivity for the leakage test procedures is established by ANSI N14.5 Section 8.4 [Ref. 71] as shown in Equation 8.3.

Equation 8.3

$$S \leq \frac{1}{2} \text{ Leakage Rate}$$

Where leakage rate is the upstream pressure leakage rate at standard conditions.

Table 8.3.2-1 RT-200 Leakage Test Types

Equipment to be Tested	ANSI N14.5 Table A1 Test Type	Test Frequency	Test Gas	Max. Leak Rate (cf. Section 4.4, Table 4.4-1)
[redacted]				
Cask Lid	A.5.3	Only once after fabrication	Helium	$\leq L_{He}$
Vent and Drain Port Cover Plates	A.5.3	Only once after fabrication	Helium	$\leq L_{He}$
Vent and Drain Ports	A.5.3	Only once after fabrication	Helium	No Leakage at a sensitivity $\leq 1\text{x}10^{-3}$ ref-cm^3/sec
Empty Cask, Cask Lid, Vent Port Cover Plate, and Drain Port Cover Plate	A.5.3	Annually, or after maintenance or repair	Helium	$\leq L_{He}$
Cask Lid and Vent and Drain Port Cover Plates[4]	A.5.1	Prior to each shipment of Type B material	Air	$\leq L_{Pu}$ or No Leakage at a sensitivity $\leq 1\text{x}10^{-3}$ ref-cm^3/sec
OR				
Cask Lid and Vent and Drain Port Cover Plates[5]	A.5.2	Prior to each shipment of Type B material	N/A (vacuum)	$\leq L_{Pu}$ or No Leakage at a sensitivity $\leq 1\text{x}10^{-3}$ ref-cm^3/sec

[redacted]

4 *The gas supply should be physically removed or powered off during the pressure measurement phase*

5 *The vacuum pump should be physically removed or powered off during the pressure measurement phase*