71-9204

CHEM-NUCLEAR SYSTEMS, LLC

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10 May, 2000
579-079-00

E. William Brach
Director, Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards, NMSS
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr.Brach:

Subject: Amendment Request for the CNS 10-160B Certificate No. 9204
Reference: CNS letter from Patrick Paquin to E. William Brach dated 7 April 2000

Chem-Nuclear submits the enclosed amendment request for the CNS 10-160B cask SAR and C of C to allow shipment of DOE TRU waste. The submittal, modeled on the RH-72B SAR and C of C, addresses the controls to be employed when shipping DOE TRU waste to assure hydrogen generated by the waste will not exceed a 5% concentration in any void in the cask. We request that you approve the revision to the SAR and revise the Certificate to reflect the following changes:

1. Chem-Nuclear is revising the SAR to include a second appendix to Chapter 4 of the SAR to specify the methods of preparation and characterization to qualify DOE generated remote-handled transuranic (RH-TRU) waste as acceptable contents for the 10-160B cask. In addition, the appendix demonstrates that RH-TRU waste forms at Battelle Columbus Laboratories (BCL) comply with content requirements.

2. We are revising pages in the Table of Contents and in Chapters 1, 3, 4, and 7 to reference the Chapter 4 appendix and reflect the methods and controls contained therein. Note that the current appendix to Chapter 4 has been repaginated; these changed pages are also included.

Also, we have included in the submittal a suggested change to the Certificate to reflect the acceptability of RH-TRU wastes as described in the new appendix.

There are several attachments to this letter, including the SAR revision pages themselves. Please note that the changes have been made to Revision 15 (the consolidated version of the SAR) which was submitted for approval on 22 March. Each attachment and its purpose are listed below:

<u>Attachment 1</u> – Replacement pages for the SAR. These pages are to be inserted as replacements for pages in Revision 15 of the current SAR.
<u>Attachment 2</u> – Additions. This is the new appendix (4.10.2.1) for Chapter 4
<u>Attachment 3</u> – Certificate addition. This is suggested language for the C of C.

As noted in the letter from DOE attached to our 7 April letter, the revision is necessary to support the Battelle Columbus Decommissioning Project. The project is scheduled to begin shipping TRU waste in the fourth quarter of 2000.

Should you or members of your staff have questions about the responses, please contact Mark Whittaker at (803)758-1898.

Sincerely,

Patrick L. Paquin
General Manager – Engineering and HLW

Attachments:
(1) Replacement Pages
(2) Appendix 4.10.2.1
(3) C of C Suggested Language

NMSS01Public

Attachment 1
Replacement Pages

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Refer to the General Arrangement Drawing of the package in Appendix 1.3. There are no complex operational requirements associated with the package.

1.2.3 Contents of Packaging

1.2.3.1 Cask Contents

The contents of the cask will consist of:

1) Greater than Type A quantities (up to a maximum of 2000 A_2) of radioactive material in the form of solids or dewatered materials in secondary containers.

2) Greater than Type A quantities (up to a maximum of 2000 A_2) of radioactive material in the form of activated reactor components or segments of components of waste from a nuclear power plant.

3) That quantity of any radioactive material which does not exceed 2000 A_2 and which does not generate spontaneously more than 100 thermal watts of radioactive decay heat.

4) The weight of the contents in the cask cavity will be limited to 14,500 lbs. If an insert is installed in the cavity, the maximum payload is reduced by the weight of the insert.

1.2.3.2 Waste Forms

The type and form of water material will include:

1) By-product, source, or special nuclear material consisting of process solids or resins, either dewatered, solid, or solidified in secondary containers. (See Section 4.2.1 for specific limitations). TRU wastes are limited as described in Appendix 4.10.2, Transuranic (TRU) Waste Compliance Methodology for Hydrogen Gas Generation.

2) Neutron activated metals or metal oxides in solid form.

3) Miscellaneous radioactive solid waste materials.

(Equation 6)

$$P_1 = \frac{T_1}{T_2} * P_2$$

$$P_1 = \frac{(460 + 168\,^\circ R)}{(460 + 70\,^\circ R)} * 14.70 \text{ PSIA}$$

$$P_1 = 17.4 \text{ PSIA}$$

The vapor pressure contributed by water in the cavity at 168°F is 5.7 psia (Reference 10). The gauge pressure in the cask under normal conditions of transport is equal to the absolute pressure of the gas mixture within the cask minus the outside ambient pressure. Equation 7 expresses the maximum gauge pressure for this cask during normal conditions of transport (MNOP).

(Equation 7) 17.4 PSIA + 5.7 PSIA - 14.7 PSIA = 8.4 PSIG

Section 2.6.1 discusses the impact of the internal pressure on cask performance. Pressure calculations for TRU waste transportation are detailed in appendix 4.10.2.

3.4.5 Maximum Thermal Stresses

The temperature gradient through the side wall under normal conditions of transport is due to the decay heat of 200 watts. The temperature difference between the outside surface of the outer shell and the inside surface of the inner steel shell is only 0.16°F on the 100°F ambient temperature. Stresses resulting from this temperature gradient are insignificant. Section 2.6.1 discusses the effect of thermal stresses in detail.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

All temperatures and stresses within the package due to normal conditions of transport are within allowable service ranges for all components and materials used in the cask. Seal temperatures range from -40 to 168°F and are within the silicone rubber operating region of -65 to 450°F. All structural materials are below their melting points.

The temperature difference between the inside surface of the inner shell and the outside surface of the outer shell is only 0.16°F. Thermal stresses resulting from this thermal gradient are discussed in section 2.6.1. The average temperature at the inside surface of the inner shell and the temperature at the outside surface of the outer shell. The average wall temperature is also used in the thermal stress calculations of section 2.6.1.

The values presented in Figure 4.8 should be used to determine the sensitivity to calibrate the leak detector prior to the test.

4.7 Periodic Verification Leak Rate Determination Using R-134A Test Gas

This section contains calculations to determine the periodic verification test measurement that is equivalent to the maximum permissible leak rate as determined using ANSI N14.5-1997 (Reference 8).

4.7.1 Introduction

The purpose of this calculation is to determine the allowable leak rate using the R-134a halogen gas that will be used as an alternative to perform the annual verification leak tests on the CNS 10-160B cask. This halogen gas is now in widespread use as a replacement gas for R-12 in many industrial applications. Properties for R134a are included in Appendix 4.10.1.

The text of this document is prepared using Mathcad, Version 6.0, software. Most conventions used in the text are the same as normal practice. A benefit of the Mathcad code is that it automatically carries all units with the variables used in the calculations. The code also allows output of variables in any form of the fundamental units (length, mass, time, etc.), allowing for automatic conversions between unit systems without the need for conversion factors. All Mathcad calculations in this Section 4.7 have been verified by hand calculations.

4.7.2 Detector Sensitivity Calculation - Test Conditions

This section determines the sensitivity necessary for a leak test performed with R-134a halogen gas. This test is performed using a General Electric Model H-25 leak detector, along with a Yokogawa Model LS-20 leak standard containing R-134a halogen gas. The leak standard is used to calibrate the leak detector to alarm at the maximum allowable test leak rate. The test is performed by filling the region between the o-rings with 25 psig of R-134a halogen gas. In section 4.2.1, it was determined that the maximum possible diameter hole in the cask O-ring (D_{max}) that would permit the standard leak rate ($L_{std} = 4.85 \times 10^{-6}$) is:

$$D_{max} = 4.17 \cdot 10^{-4} \cdot cm$$

Next, determine the equivalent air/R134a mixture (L_{mix}) that would leak from D_{max} during a leak test. The O-ring void is pressurized to 25 psig (2.7 atm) with an air/R134a mixture.

$$P_{mix} = 2.7 \cdot atm$$

$$P_{air} = 1.0 \cdot atm$$

$$P_{R134a} = 1.7 \cdot atm$$

$$P_a = \frac{P_{mix} + P_{air}}{2} \Rightarrow \qquad P_a = 1.85\, atm$$

The properties of R134a are given in the attached literature (Appendix 4.10.1).

$$M_{R134a} = 102 \cdot \frac{gm}{mole}$$ Appendix 4.10.1

$$\mu_{R134a} = 0.012 \cdot cP$$ Appendix 4.10.1

$$M_{mix} = \frac{M_{R134a} \cdot P_{R134a} + M_{air} \cdot P_{air}}{P_{mix}}$$ Eqn. B7 - ANSI N14.5

$$\Rightarrow \qquad M_{mix} \ 74.96 \frac{gm}{mole}$$

$$\mu_{mix} = \frac{\mu_{air} \cdot P_{air} + \mu_{R134a} \cdot P_{R134}}{P_{mix}}$$ Eqn. B8 - ANSI N14.5

$$\Rightarrow \qquad \mu_{mix} = 0.014\ cP$$

Next, determine L_{mix} as a function of temperature. The viscosities of air and R134a do not change significantly over the range of temperatures evaluated:

$$T = 273 \cdot K, 278 \cdot K .. 318 \cdot K$$ Temperature range for test: 32°F to approx. 113°F

Substitute these properties for the air/R134a mixture and the maximum diameter hole (D_{max}) into equations Eqn. B.3, B.4, and B.5 from ANSI N14.5:

volume under test, i.e. the 0063 gram moles per cubic foot relationship to a 2.3 psi pressure rise is valid for one or many cubic feet of specimen volume). This incremental pressure rise is an inconsequential load on the cask structure. Methodology for demonstrating compliance with the 5% hydrogen concentration limit for TRU wastes is described in Appendix 4.10.2, Transuranic (TRU) Waste Compliance Methodology for Hydrogen Gas Generation.

(Ref. 7), Criteria (ii) is invoked to ensure that when a secondary container's hydrogen concentration potentially exceeds 5% volume, release of that hydrogen to the then existing total volume (secondary container void plus cask void) will not result in a total mixture of greater than 5% volume hydrogen in a greater than 5% oxygen atmosphere. Maintaining the oxygen concentration lower than five (5) volume % assures a nonflammable mixture.

4.10 Appendices

Appendix 4.10.1

Properties of R-134a

DUPONT

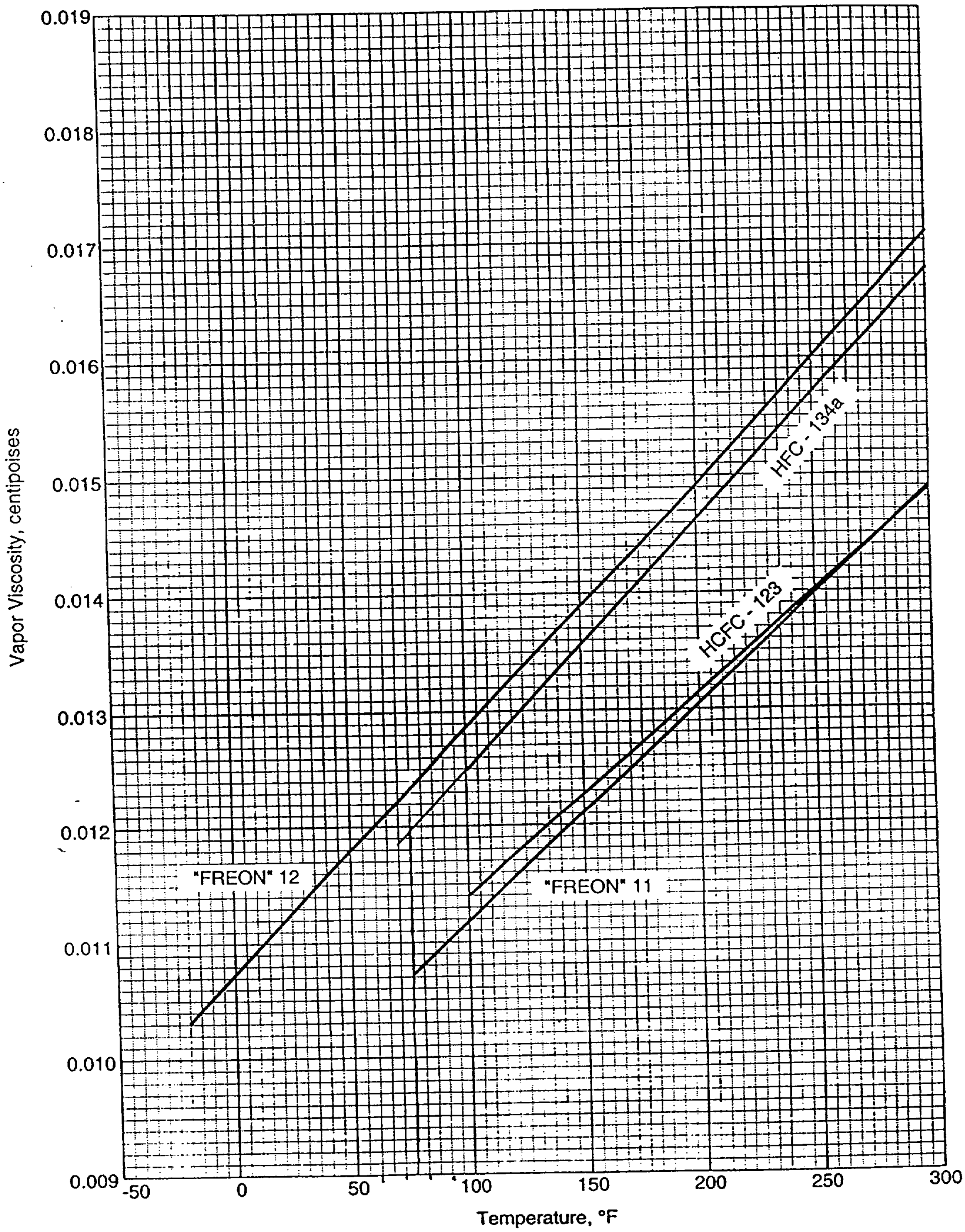
Suva®
refrigerants

DuPont HFC-134a

Properties, Uses, Storage and Handling

Suva 134a refrigerant
Suva 134a (Auto) refrigerant
Formacel® Z-4 foam expansion agent
Dymel® 134a aerosol propellant
Dymel 134a/P aerosol propellant

Vapor Viscosity at Atmospheric Pressure



SUVA®

Rev. 16
5/2000

REFRIGERANTS

PRODUCT INFORMATION

Transport Properties of SUVA® Refrigerants:

SUVA® COLD - MP (HFC - 134a)
SUVA® TRANS A/C (HFC - 134a)
SUVA® CENTRI - LP (HCFC - 123)

Viscosity
Thermal Conductivity
and
Heat Capacity
for the
Liquid and Vapor

DUPONT

Table 2
Physical Properties of HFC-134a

Physical Properties	Units	HFC-134a
Chemical Name	—	Ethane, 1,1,1,2-Tetrafluoro
Chemical Formula	—	CH_2FCF_3
Molecular Weight	—	102.03
Boiling Point at 1 atm (101.3 kPa or 1.013 bar)	°C °F	−26.1 −14.9
Freezing Point	°C °F	−103.3 −153.9
Critical Temperature	°C °F	101.1 213.9
Critical Pressure	kPa lb/in.² abs	4060 588.9
Critical Volume	m³/kg ft³/lb	1.94×10^{-3} 0.031
Critical Density	kg/m³ lb/ft³	515.3 32.17
Density (Liquid) at 25°C (77°F)	kg/m³ lb/ft³	1206 75.28
Density (Saturated Vapor) at Boiling Point	kg/m³ lb/ft³	5.25 0.328
Heat Capacity (Liquid) at 25°C (77°F)	kJ/kg·K or Btu/(lb) (°F)	1.44 0.339
Heat Capacity (Vapor at Constant Pressure) at 25°C (77°F) and 1 atm (101.3 kPa or 1.013 bar)	kJ/kg·K or Btu/(lb) (°F)	0.852 0.204
Vapor Pressure at 25°C (77°F)	kPa bar psia	666.1 6.661 96.61
Heat of Vaporization at Boiling Point	kJ/kg Btu/lb	217.2 93.4
Thermal Conductivity at 25°C (77°F)		
Liquid	W/m·K Btu/hr·ft°F	0.0824 0.0478
Vapor at 1 atm (101.3 kPa or 1.013 bar)	W/m·K Btu/hr·ft°F	0.0145 0.00836
Viscosity at 25°C (77°F)		
Liquid	mPa·S (cP)	0.202
Vapor at 1 atm (101.3 kPa or 1.013 bar)	mPa·S (cP)	0.012
Solubility of HFC-134a in Water at 25°C (77°F) and 1 atm (101.3 kPa or 1.013 bar)	wt %	0.15
Solubility of Water in HFC-134a at 25°C (77°F)	wt %	0.11
Flammability Limits in Air at 1 atm (101.3 kPa or 1.013 bar)	vol %	None
Autoignition Temperature	°C °F	770 1418
Ozone Depletion Potential	—	0
Halocarbon Global Warming Potential (HGWP) (For CFC-11, HGWP = 1)	—	0.28
Global Warming Potential (GWP) (100 yr. ITH. For CO_2, GWP = 1)	—	1200
TSCA Inventory Status	—	Reported/Included
Toxicity AEL[a] (8- and 12-hr TWA)	ppm (v/v)	1000

[a] AEL (Acceptable Exposure Limit) is an airborne inhalation exposure limit established by DuPont that specifies time-weighted average concentrations to which nearly all workers may be repeatedly exposed without adverse effects.

Note: kPa is absolute pressure.

Appendix 4.10.2

Transuranic (TRU) Waste Compliance
Methodology for Hydrogen Gas Genration

7.0 OPERATING PROCEDURE

This chapter describes the general procedure for loading and unloading of the CNS 10-160B cask.

An optional steel insert may be used to shield the contents of the cask. The appropriate thickness of insert that should be used is determined from calculations and experience with previous, similar shipments. However, the insert must be thick enough so that dose rates on the exterior of the cask do not exceed the limits of 10 CFR 71.47, but must be no thicker than the maximum permissible size described in section 1.0.

The maximum permissible payload of the cask is 14,500 pounds, including contents, secondary containers, shoring, and optional steel insert (if used).

For contents that could radiolytically generate combustible gases, the criteria of Section 4.8 must be addressed. For DOE TRU wastes, compliance with the 5% hydrogen concentration limit shall be demonstrated by the methods discussed in Appendix 4.10.2. For other contents which exceed the 5% concentration limit, the procedures in Section 7.4 can be used to satisfy the criteria of Section 4.8.

7.1 Procedure for Loading the Package

7.1.1 Determine if cask must be removed from trailer for loading purposes. To remove cask from trailer:

7.1.1.1 Loosen and disconnect ratchet binders from upper impact limiter.

7.1.1.2 Using suitable lifting equipment, remove upper impact limiter. Care should be taken to prevent damage to impact limiter during handling and storage.

7.1.1.3 Disconnect cask to trailer tie-down equipment.

7.1.1.4 Attach cask lifting ears and torque bolts to 200 ft-lbs $\pm$ 20 ft-lbs lubricated.

7.1.1.5 Using suitable lifting equipment, remove cask from trailer and lower impact limiter and place cask in level loading position.

NOTE **THE CABLES USED FOR LIFTING THE CASK MUST HAVE A TRUE ANGLE, WITH RESPECT TO THE HORIZONTAL OF NOT LESS THAN 60^{O}.**

Attachment 2
Appendix 4.10.2.1

Appendix 4.10.2.1

Compliance Methodology for RH-TRU Waste From
Battelle Columbus Laboratories (BCL)
West Jefferson, OH

1.0 SUMMARY

The purpose of this appendix is to identify acceptable methods of preparation and characterization to qualify remote-handled transuranic (RH-TRU) waste, as defined by the U.S. Department of Energy (DOE) (Ref. 12.1), as payload for transport in the CNS 10-160B cask and to demonstrate that the RH-TRU waste forms at Battelle Columbus Laboratories (BCL), described in this appendix, comply with the payload requirements.

The payload parameters that are controlled in order to ensure safe transport of the RH-TRU waste in the CNS 10-160B cask are as follows:

Restrictions on the physical and chemical form of RH-TRU waste.

Restrictions on payload materials to ensure chemical compatibility among all constituents in a particular CNS 10-160B cask (including the parts of the cask that might be affected by the payload).

Restrictions on the maximum pressure in the CNS 10-160B cask during a 60-day period. (As a conservative analysis, the maximum pressure calculations are performed for a period of one year.)

Restrictions on the amount of potentially flammable gases that might be present or generated in the payload during a 60-day transport period.

Restrictions on the layers of confinement for RH-TRU waste materials in the waste containers packaged in the cask.

Restrictions on the fissile material content for the cask.

Restrictions on the hydrogen generation rates or the decay heat for the waste containers packaged in the cask.

Restrictions on the weight for the waste containers and the loaded cask.

This appendix provides allowable methods to prepare payloads to meet these restrictions. The methods for determining or measuring each restricted parameter, the factors influencing the parameter values, and the methods used by BCL for demonstrating compliance, are provided in the following sections.

This appendix also includes the following as attachments:

Content codes BC 312A, BC 314A, BC 321A, BC 321B, and BC 322A (Attachment A)
Chemical Lists for the above mentioned content codes (Attachment A)
Methods for Determining Gas Generation Rates and Decay Heat Values (Attachment B).

2.0 INTRODUCTION

2.1 Purpose

The purpose of this appendix is to describe the acceptable methods that shall be used to prepare and characterize the RH-TRU waste belonging to BCL prior to transport in the CNS 10-160B cask. It incorporates acceptable methods applicable to the content codes listed in Table 3-1 of this appendix.

These methods will be expanded, as necessary, to incorporate additional waste content codes that may be identified in the future.

Section 2.2 lists the payload parameters that shall be determined for each payload. Section 3.0 describes the relationship between payload parameters and the classification of RH-TRU materials into CNS 10-160B cask payload content codes. Sections 4.0 through 10.0 discuss each payload parameter, the allowable method(s) for demonstrating compliance with the CNS 10-160B cask payload requirements, and the controls that are required for acceptable implementation of these method(s).

2.2 Payload Parameters

The payload parameters addressed in this document include:

Physical form
Chemical form and chemical properties
Chemical compatibility
Gas distribution and pressure buildup
Payload container and contents configuration
Isotopic characterization and fissile content
Decay heat and hydrogen generation rates
Weight.

3.0 TRU WASTE PAYLOAD FOR CNS 10-160B CASK

RH-TRU waste is classified into content codes, which give a description of the RH-TRU waste material in terms of processes generating the waste, the packaging methods used in the waste container(s), and the generating site. Content codes for the RH-TRU waste from BCL are provided in Attachment A and are listed in Table 3-1. For each content code, Attachment A provides a listing of all payload parameters, their corresponding limits and restrictions, and the methods used by BCL to meet these limits.

Table 3-1. BCL Content Codes

Content Code	**Waste Form Description**
BC 312A	Solidified Organic Waste (R&D operations)
BC 314A	Cemented Inorganic Process Solids (R&D operations)
BC 321A	Solid Organic Waste (D&D operations)
BC 321B	Solid Organic Waste (Pool filters and resins)
BC 322A	Solid Inorganic Waste (R&D operations)

D&D = Decontamination and decommissioning.
R&D = Research and development.

The BCL has developed a formal TRU waste certification program that ensures the generation and packaging of waste under rigorous controls and documented procedures, in compliance with all governing regulations. In addition, complete documentation packages, along with quality assurance/quality control records, are generated for all payload containers. All TRU waste generated from the BCL will be packaged under a formal certification program. TRU waste generated from the BCL will comply with all transportation requirements using the following methods:

Formally documented acceptable knowledge of the processes generating the waste

Audio/video surveillances of all packaging activities conducted in accordance with approved procedures that ensure the absence of prohibited items and compliance with packaging requirements

Data packages generated for all payload containers that document the contents and properties of the waste in the container

Measurement of required parameters (weight, etc.) to ensure compliance with limits.

4.0 PHYSICAL FORM

4.1 Requirements

The physical form of waste comprising the CNS 10-160B cask payload is restricted to solid or solidified materials in secondary containers or activated reactor components. The total volume of residual liquid in a secondary container is restricted to less than 1% by volume. Secondary containers or components must be shored to prevent movement during accident conditions. Sealed or pressurized containers greater than four liters in size are prohibited.

4.2 Methods of Compliance and Verification

Compliance with the physical form requirements is determined by acceptable knowledge (AK).

Battelle Columbus Laboratories Decommissioning Program (BCLDP) TRU Waste Certification Program (WCP) personnel shall ensure compliance with the liquids requirement using AK documentation collected under TCP-98-03, Building JN-1 Hot Cell Laboratory Acceptable Knowledge Document, and TCP-98-03.1, TRU Waste Process Descriptions, and verified under TC-OP-01.4, Segregation and Packaging of TRU Waste. BCLDP TRU WCP personnel shall restrict the presence of free liquids in the payload containers to the extent that is reasonably achievable. Under TC-OP-01.4, Segregation and Packaging of TRU Waste, BCLDP TRU WCP personnel shall visually inspect payload containers during packaging to ensure the absence of free liquids. BCLDP TRU WCP personnel shall document the absence of free liquids in the payload container data package.

BCLDP TRU WCP personnel shall ensure compliance with the requirement associated with sharp or heavy objects through visual examination at the time of packaging as described in TC-OP-01.4, Segregation and Packaging of TRU Waste.

BCLDP TRU WCP personnel shall ensure compliance with the requirement associated with sealed containers through visual examination at the time of packaging as described in TC-OP-01.4, Segregation and Packaging of TRU Waste.

5.0 CHEMICAL FORM AND CHEMICAL PROPERTIES

5.1 Requirements

The chemical properties of the waste are determined by the chemical constituents allowed in a given content code. Specific requirements regarding the chemical form of the waste are as follows:

Explosives, nonradioactive pyrophorics, compressed gases, and corrosives are prohibited.

Pyrophoric radionuclides may be present only in residual amounts less than 1 weight percent.

The total amount of potentially flammable volatile organic compounds (VOCs) present in the headspace of a secondary container is restricted to 500 parts per million (ppm).

5.2 Methods of Compliance and Verification

Compliance with chemical form and chemical property restrictions is demonstrated through process knowledge or sampling programs, if required.

5.2.1 Pyrophoric Materials

Nonradioactive pyrophoric materials shall not be packaged into payload containers. Radioactive pyrophoric material, if present in the waste stream, shall be limited to less than 1 percent (weight) of the payload container. In accordance with TC-OP-01.4, Segregation and Packaging of TRU Waste, qualified BCLDP TRU WCP personnel shall use AK information in conjunction with visual examination during waste generation and packaging to verify the absence of nonradioactive pyrophoric materials (e.g., according to records of waste generation processes, nonradioactive pyrophoric materials have not been used). As described in TC-AP-01.1, TRU Waste Data Package Generation, the absence of nonradioactive pyrophorics shall be recorded in the payload container data package. Any nonradioactive pyrophorics encountered during examination shall be segregated and shall not be shipped.

5.2.2 Explosives, Corrosives, and Compressed Gases

In accordance with TC-OP-01.4, Segregation and Packaging of TRU Waste, qualified BCLDP TRU WCP personnel shall use AK information in conjunction with visual examination during waste generation and packaging to verify the absence of explosives, corrosives, and compressed gases. Any unvented compressed gas canisters (including aerosol cans) identified during the packaging of wastes shall be segregated as described in TC-OP-01.4, Segregation and Packaging of TRU Waste. Acids and bases, if found, shall be neutralized. The absence of explosives, unvented compressed gas canisters, and corrosives shall be documented in the payload container data packages by BCLDP TRU WCP personnel as described in TC-AP-01.1, TRU Waste Data Package Generation.

5.2.3 Flammable VOCs

All TRU waste from the BCL is from research and development or decontamination and decommissioning related activities and will be packaged with the generation of complete data packages. Most of the BCL content codes are not expected to have flammable VOCs based on the content codes, the waste packaging process (sorted and repackaged into drums as individual items, which would minimize the introduction of VOCs into the drums), and the lack of a source for the VOCs. For content codes that could potentially have flammable VOCs (e.g., BC 312A), AK will be used to ensure compliance with the flammable VOC limit. If AK is not available, a suitable testing program will be used to ensure compliance.

6.0 CHEMICAL COMPATIBILITY

6.1 Requirements

Each content code has an associated chemical list (Attachment A) based on AK information. Chemical constituents in a payload container assigned to a given content code shall conform to these approved chemical lists. Chemicals/materials that are not listed are allowed in trace amounts (quantities less than 1 percent [weight]) in a payload container provided that the total quantity of trace chemicals/materials is restricted to less than 5 percent (weight). Qualified BCLDP TRU WCP personnel will evaluate the content code assignment, including chemical lists, for each payload container as described in TC-OP-01.4, Segregation and Packaging of TRU Waste.

Chemical compatibility of a waste with its packaging ensures that chemical reactions will not occur that might pose a threat to the safe transport of a payload in the CNS 10-160B cask.

6.2 Methods of Compliance and Verification

Chemical compatibility analyses for all authorized payloads is performed according to a U.S. Environmental Protection Agency method (Ref. 12.2). Chemical compatibility for the content code chemical lists is ensured by these analyses. Qualified BCLDP TRU WCP personnel shall document the presence of any chemicals identified during the waste characterization process in the payload container data packages. TC-OP-01.4, Segregation and Packaging of TRU Waste, includes instructions for comparing chemicals noted in the payload container data packages against the chemicals listed in the appropriate content code to ensure the contents of payload containers are compatible.

7.0 GAS DISTRIBUTION AND PRESSURE BUILDUP

7.1 Requirements

Gas distribution and pressure buildup during transport of TRU waste in the CNS 10-160B cask payload are restricted to the following limits:

The gases generated in the payload must be controlled to prevent the occurrence of potentially flammable concentrations of gases within the payload confinement layers and the void volume of the inner vessel (IV) cavity. Specifically, hydrogen concentrations within the payload confinement layers are limited to 5 percent by volume during a maximum 60-day shipping period (twice the expected shipping time of 30 days).

The gases generated in the payload and released into the IV cavity must be controlled to maintain the pressure within the IV cavity below the acceptable packaging design limit of 31.2 pounds per square inch gauge (psig).

7.2 Methods of Compliance and Verification

The primary mechanism for gas generation during TRU waste transportation in the CNS 10-160B cask is by radiolysis of the waste materials. Gas generation from other mechanisms such as chemical, thermal, or biological activity is expected to be insignificant for the TRU waste payload. As discussed in Section 6.0, the chemicals and materials in the TRU waste are compatible and inert, and the restrictions of the materials that can be present in each content code precludes the occurrence of chemical reactions that can produce excessive gas. Gas generation from biological activity is expected to be insignificant given the transportation time, the nature of the waste (solid or solidified), and the environment of the payload (lack of nutrients, lack of water content, etc.). The temperatures of the payload, given the decay heat limits applicable, are expected to be below the normal usage range for the payload materials, resulting in very little potential for gas generation due to thermal decomposition.

Compliance with the CNS 10-160B cask design pressure limit for each content code is analyzed by assuming that all gases generated are released into the IV cavity and by including the contributions from thermal expansion of gases and vapor pressure of atmospheric water.

Table 7-1 shows that the pressure increase during a period of 365 days is below the design pressure limit of 31.2 psig for all the BCL content codes.

Table 7-1. Maximum Pressure Increase Over 365-Day Shipping Period

Content Code	Geff (RT)a	Void Volume (Liters)	Activation Energy	Decay Heat Limit (Watts)	Geffb	Pmaxc (psig)
BC 312Ad	—	—	—	—	—	—
BC 314A	0.72	1938	0	7.38	0.72	12.09
BC 321A	8.4	1938	2.1	1.58	14.71	24.85
BC 321B	8.4/2.1e	1938	2.1	2.69	4.7	17.32
BC 322A	0.024	1938	0	221	0.024	12.08

aG value for net gas (molecules per 100 eV) at room temperature (70 F).
bEffective G value (molecules per 100 eV) at maximum operating temperature of 168 F calculated using the Arrhenius equation for which activation energy is an input.
cMaximum pressure.
dThis code consists of solidified organics; compliance with pressure limits will be shown by testing.
eBC 321B reports 12% cellulosics and 80% resins (remainder being inorganic material) and is reflected in the calculation of the temperature-corrected Geff.

Compliance with the restrictions on flammable gas concentration is discussed in Section 10.0.

8.0 PAYLOAD CONTAINER AND CONTENTS CONFIGURATION

8.1 Requirements

Fifty-five-gallon drums are authorized payload containers in a CNS 10-160B cask. Up to ten 55-gallon drums of RH-TRU waste may be packaged in the cask. Each 55-gallon drum to be packaged in the CNS cask must have a minimum of one filter vent. The minimum filter vent specifications for the 55-gallon drums and drum liners used to package waste inside the drums are provided in Table 8-1.

Table 8-1. Minimum Filter Vent Specifications

Container Type	Filter Specification			
	Number of Vents Required per Container	Flow Rate (ml/min of air, STP, at 1 inch of water)a	Efficiency (percent)	Hydrogen Diffusivity (mol/s/mol fraction at 25 C)
Drum	1	35	99.5	3.70E-6
Drum Liner Filter	1	35	NAb	3.70E-6

aFilters tested at a different pressure gradient shall have a proportional flow rate (e.g., 35 ml/min at 1 inch of water = 1 L/min at 1 psi).
bFilters installed in containers that are overpacked are exempt from the efficiency requirement as the drum must exhibit a 99.5 percent efficiency.
NA = Not applicable

The test methods used to determine the compliance of filter vents with the performance-based requirements of flow rate, efficiency, and hydrogen diffusivity shall be directed by procedures under a quality assurance program.

Filter vents shall be legibly marked to ensure both (1) identification of the supplier and (2) date of manufacture, lot number, or unique serial number.

8.2 Methods of Compliance and Verification

Procured filter vents at BCL shall be inspected as directed by QD-AP-04.1, Documentation and Control of Purchased Items and Services, to verify compliance with the applicable filter vent specifications specified in the purchase requisition (i.e., visual inspection of certificate of conformance serial numbers to actual filter vents and inspection of filters for physical damage). Under WA-OP-006, Procurement and Inspection of Packagings for Hazardous Materials Shipments, payload containers shall be visually inspected to ensure that they have been fitted with the required number of filter vents as specified above. Nonconforming filter vents shall be segregated in accordance with QD-AP-15.1, Nonconformance Reporting for Activities, Items and Materials. As described in TC-OP-01.4, Segregation and Packaging of TRU Waste, qualified BCLDP TRU WCP personnel also shall visually inspect payload containers during packaging to ensure that each has been fitted with the correct type and number of filter vents.

Prior to transport, payload container filter vents shall be visually inspected by the Transportation Certification Official (TCO) for damage or defect. If a defect is identified, a nonconformance report shall be issued in accordance with QD-AP-15.1, Nonconformance Reporting for Activities, Items and Materials, and the payload container shall be returned for repackaging or overpacking prior to certification.

9.0 ISOTOPIC CHARACTERIZATION AND FISSILE CONTENT

9.1 Requirements

The CNS 10-160B cask payload allows fissile materials, provided the mass limits of Title 10, Code of Federal Regulations, Section 71.53 are not exceeded. Plutonium content cannot exceed 0.74 Bq (20 curies) per cask.

9.2 Methods of Compliance and Verification

BCLDP TRU WCP personnel will calculate the fissile or fissionable radionuclide content of the payload container as Pu-239 (plutonium-239) fissile gram equivalents (FGE) and as plutonium curies as described in TC-AP-01.2, Calculations Using Radioassay Data. These calculations are based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. As described in DD-98-04, Waste Characterization, Classification and Shipping Support Technical Basis Document, assay of samples and dose rate measurements, along with the appropriate isotopic composition, are used to determine the isotopic inventory. The TCO shall evaluate the compliance of the total FGE value and the plutonium curies of payload containers with the maximum limits.

It should be noted that BCLDP accountability records indicate no more than approximately 50 grams of fissile material is dispersed throughout the West Jefferson North facility in low isotopic enrichments (Ref. 12.3). Therefore, the drum loading of fissile material will be much lower.

10.0 DECAY HEAT AND HYDROGEN GAS GENERATION RATES

This section describes the logic and methodology used in evaluating payload characteristics that meet the hydrogen gas concentration requirement for each of the RH-TRU content codes for the BCL RH-TRU wastes described in this section.

10.1 Requirements

The hydrogen gas concentration shall not exceed 5% by volume in all void volumes within the CNS 10-160B cask payload during transport up to twice the expecting shipping time of 30 days.

10.2 Methodology of Ensuring Compliance with Flammable Gas Concentration Limits

Section 7.2 demonstrates that chemical, biological, and thermal gas generation mechanisms are insignificant in the CNS 10-160B cask. In addition, as shown in Section 5.1, potentially flammable VOCs are restricted to 500 ppm in the headspace of the CNS 10-160B cask secondary containers. Therefore, the only flammable gas of concern for transportation purposes is hydrogen. The concentration of hydrogen within any void volume in a layer of confinement of the payload or in the cask IV has been evaluated during a 60-day shipping period (i.e., twice the expected shipping duration).

Attachment A provides the RH-TRU waste content codes for the BCL RH-TRU wastes that are included in the authorized payload for the CNS 10-160B cask. Each content code has a unique and completely defined packaging configuration. Modeling the movement of hydrogen from the waste material to the payload voids, using the release rates of hydrogen through the various confinement layers, defines the relationship between generation rate and void concentration. This modeling allows determination of the maximum allowable hydrogen generation rate for a given content code to meet the 5% concentration limit, as detailed in Section 10.3. Based on hydrogen gas generation potential, quantified by hydrogen gas generation G values, the gas concentration limit can be converted to a decay heat limit, as detailed in Section 10.4. The maximum allowable hydrogen generation rates and decay heat limits for the RH-TRU content codes for BCL wastes are listed in Table 10-1.

Table 10-1. Maximum Allowable Hydrogen Gas Generation Rates, Decay Heat Limits, and Total Activity Limits

Content Code	**Maximum Allowable Hydrogen Gas Generation Rate, mole/second/drum**	**Maximum Allowable Hydrogen Gas Generation Rate, moles/second/cask**	**Maximum Allowable Decay Heat Limit, Watts/Drum**	**Maximum Allowable Decay Heat Limit, Watts/Cask**	**Maximum Total Activity Limit Curies/Cask[a]**
BC 312A	3.5082E-8	3.5082E-7	—[b]	—[b]	—[b]
BC 314A	3.5082E-8	3.5082E-7	0.738	7.38	1.45E+3
BC 321A	4.093E-8	4.093E-7	0.158	1.58	2.83E+2
BC 321B	4.093E-8	4.093E-7	0.269	2.69	5.76E+2
BC 322A	3.5082E-8	3.5082E-7	22.1	221	3.96E+4

[a]Other limits applicable to the cask (not related to gas generation) shall also be met.
[b]No decay heat limit or activity limit due to unknown G value.

Two methods are available to demonstrate compliance with the 5% concentration limit: 1) determine the actual hydrogen generation rate for payload containers and show that this rate is less than the maximum allowable rate, and 2) determine the radioactivity in the payload container and demonstrate that this radioactivity will result in a decay heat less than a decay heat limit established for each content code. Since radiolysis is the primary method by which hydrogen is generated, the maximum allowable generation rate can be reduced to a decay heat limit, by use of G values as discussed in Section 10.4. These two methods are described in detail in subsequent sections.

Parameters that govern the maximum allowable hydrogen generation rates and maximum allowable decay heat limits are listed below:

- Waste packaging configuration (i.e., the number and type of confinement layers).

- Release rates of hydrogen from each of these confinement layers.

- Void volume in the IV available for gas accumulation.

- Operating temperature and pressure for the payload in the CNS cask IV during the maximum shipping period.

- Duration of the shipping period.

- Fraction of the gamma energy absorbed by waste materials that could potentially generate hydrogen.

- Hydrogen generation rates quantified by the G value of a waste material (the number of molecules of hydrogen produced per 100 eV of energy absorbed).

10.3 Determination of Maximum Allowable Hydrogen Generation Rates for Content Codes

The modeling for determination of the maximum allowable generation rates is described below.

10.3.1 Input Parameters

The model parameters that must be quantified include the following:

Waste Packaging Configuration and Release Rates: Each content code has a unique packaging configuration that is completely defined. Packaging configurations for the proposed content codes for BCL are identical. The waste will be placed directly into a 55-gallon drum that may be lined with a steel liner. Ten drums will then be placed into the CNS 10-160B cask. Release rates of hydrogen through the drum filters and drum liner filters have been quantified, and are summarized in Table 10-2. These are based on release rates obtained for filters (Ref. 12.4) at room temperatures. The release rates used in the calculations are the minimum measured values in each case. The release rates in Table 10-2 are shown for two different temperatures. The temperature dependence of these release rates is discussed later in this section.

Void Volumes in Confinement Layers: The void volumes in the confinement layers are content code specific. The void volumes for the layers in the different content codes are based on waste generation processes and the specific contents within the content codes. This section summarizes the void volumes within the confinement layers for the various content codes. In all cases, a conservative (i.e., minimal) void volume has been used.

Table 10-2. Release Rates of Hydrogen

Content Code	Filter Type	Release Rate (mol/sec/mol fraction) T = 233K	T = 348.6K
	Drum Liner Filter	2.46 x 10-6	4.98 x 10-6
BC 312A	Drum Filter	2.46 x 10-6	4.98 x 10-6
	Drum Liner Filter	2.46 x 10-6	4.98 x 10-6
BC 314A	Drum Filter	2.46 x 10-6	4.98 x 10-6
	Drum Liner Filter	2.46 x 10-6	4.98 x 10-6
BC 321A	Drum Filter	2.46 x 10-6	4.98 x 10-6
	Drum Liner Filter	2.46 x 10-6	4.98 x 10-6
BC 321B	Drum Filter	2.46 x 10-6	4.98 x 10-6
	Drum Liner Filter	2.46 x 10-6	4.98 x 10-6
BC 322A	Drum Filter	2.46 x 10-6	4.98 x 10-6

Cask Void Volume: The cask will have a payload of 10 drums and a drum carriage. The interior volume of the cask, Vcask, is 4438 liters. The volume occupied by the drum carriage, Vcarriage, is 143.2 liters. The external volume of a single drum, Vdrum, is 235.7 liters. The void volume within the cask is calculated as:

$$V_{V,cask} = V_{cask} - V_{carriage} - 10\ V_{drum}$$

$$V_{V,cask} = 4438\ liters - 143.2\ liters - 10\ (235.7\ liters)$$

$$V_{v,cask} = 1938\ liters$$

Drum Headspace Void Volume: The internal height of the cylindrical 55-gallon drum is 33.25 inches (in.) and the inside diameter is 22.5 in. The internal volume of the drum is thus calculated as:

$$V_{drum,Internal} = \pi\ r^2_{drum,Internal}\ h_{drum,Internal}$$

$$V_{drum,Internal} = \pi \, (\frac{22.5 \, in}{2} \, x \, 2.54 \, cm/in)^2 (33.25 \, in \, x \, 2.54 \, cm/in)$$

$$V_{drum,Internal} = 216{,}644 \, cm^3 = 216.6 \, liters$$

The external height of the cylindrical drum liner is 32.250 in., and the outside diameter is 19.500 in. The external volume of the drum liner is calculated as:

$$V_{liner,external} = \pi \, r^2_{liner,external} \, h_{liner,external}$$

$$V_{liner,external} = \pi \, (\frac{19.5 \, in}{2} \, x \, 2.54 \, cm/in)^2 (32.25 \, in \, x \, 2.54 \, cm/in)$$

$$V_{liner,external} = 157{,}830 \, cm^3 = 157.8 \, liters$$

The void volume within the drum headspace, VV,hs, is calculated as:

$$V_{V,hs} = V_{drum,Internal} - V_{liner,External}$$

$$V_{V,hs} = 216.6 \, liters - 157.8 \, liters$$

$$V_{V,hs} = 58.8 \, liters$$

Drum Liner Void Volume:

Content Codes BC 321A and BC 321B

These content codes are comprised of combustible, debris type of waste materials. The drum liner thickness is 0.105 in. The external height of the cylindrical drum liner is 32.250 in., and the outside diameter is 19.500 in. The internal dimensions of the rigid liner are thus a height of 32 in. and a diameter of 19.3 in. The internal volume of the drum liner is calculated as:

$$V_{liner,Internal} = \pi \, r^2_{liner,Internal} \, h_{liner,Internal}$$

$$V_{liner,Internal} = \pi \, (\frac{19.3 \, in}{2} \, x \, 2.54 \, cm/in)^2 (32 \, in \, x \, 2.54 \, cm/in)$$

$$V_{liner,Internal} = 153{,}400\, cm^3 = 153.4\ liters$$

Based on density data of residential, commercial, and combustible mixed construction debris from Reference 12.5, the bulk density of the waste materials, b ulk, in content codes BC 321A and BC 321B is 0.36 g/cm3. The solid material density, solid, of these materials is 0.70 g/cm3. Thus, the minimum porosity, , is calculated as:

$$\varepsilon = 1 - \frac{0.36}{0.70}$$

$$\varepsilon = 0.486 = 48.6\%$$

Thus, the minimum void volume within the rigid liner, VV,liner, is calculated as:

$$V_{V,liner} = 0.486\ (153.4\ liters)$$

$$V_{V,liner} = 73.6\ liters$$

Content Codes BC 312, BC 314, and BC 322

A conservative void volume of 1 liter within the drum liner is used in the calculations of maximum allowable hydrogen gas generation rates for these content codes.

Pressure: The pressure is assumed to be isobaric and equal to one atmosphere. The mole fraction of hydrogen in each void volume would be smaller if pressurization is considered and would result in a greater maximum allowable hydrogen gas generation rate. Furthermore, the amount of hydrogen gas generated during a sixty day shipping period would be negligible compared to the quantity of air initially present at the time of sealing the CNS 10-160B cask.

Temperature: The input parameter affected by temperature is the release rate through the different confinement layers in the payload containers and the G values for hydrogen. For the RH-TRU waste content codes, these are the filters in the inner containers. These release rates increase with increasing temperature (Ref. 12.6). Therefore, the minimum release rates would be those at the lowest operating temperature. These are the release rates indicated in Table 10-2 for 233K. The minimum decay heat limits are determined by the ratio of the release rates and the G values. In other words, the higher the release rates, the higher the decay heat limit; the higher the G value, the lower the decay heat limit. The dependence of G values on temperature is documented in Section 10.4. For determining the decay heat limit, the temperature that yielded the minimum decay heat limit for each content code was used as the input parameter.

In summary, the temperature dependence of the input parameters was accounted for in the calculation so that, in each case, the minimum possible limit (hydrogen generation rate or decay heat limit) was obtained. This provides an additional margin of safety in the analysis for each content code.

These are the important input parameters for determining the maximum allowable hydrogen generation limits. Other assumptions used in the mathematical analysis are included in Section 10.3.2.

10.3.2 Mathematical Analysis For Determining the Maximum Allowable Hydrogen Gas Generation Rates

The maximum allowable gas generation rate for each content code was calculated using numerical solutions to differential equations, which describe the unsteady-state (i.e., transient) mass balances on hydrogen within each confinement volume of the CNS 10-160B cask. The hydrogen generation rate which will yield 5 volume percent within the innermost layer of confinement is not known a priori and is calculated using an iterative scheme which is described below.

The assumptions that have been made in deriving the governing equations are as follows:

- Hydrogen is an ideal gas and the ideal gas law applies.
- The hydrogen is assumed to be nonreactive with any materials in the payload container.
- Hydrogen gas generation rates are not reduced by depletion of the waste matrix.
- The concentration of hydrogen within each of the layers of confinement prior to transport in the CNS 10-160B cask is assumed to be at steady-state (generation rate equals release rate). This assumption provides an additional margin of safety since the concentrations of hydrogen are maximum at steady-state conditions.

The following list defines the variables which are used in the description of the mathematical framework.

X1 = Mole fraction hydrogen within the innermost confinement volume.

Xi = Mole fraction hydrogen in the confinement volume "i".

Rdf = The effective release rate of hydrogen across the filter on a drum (L/day).

Rlh = The effective release rate of hydrogen across the drum liner filter (L/day).

Vi = The void volume within confinement layer "i" (L).

t = Time (days).

R = The gas law constant (0.08206 atm L mol-1 K-1).

T = Absolute temperature (K).

P = Absolute pressure (atm).

CG = The hydrogen gas generation rate per innermost confinement layer in one drum(mol/sec).

For brevity in subsequent discussions, a parameter C1 will be defined as:

C1 = CG x R x T / (P x V1)

The evaluation of maximum allowable hydrogen gas generation rates was performed through iterative calculations until the appropriate hydrogen gas generation rate per drum yielded a concentration of 0.05 mole fraction within the innermost layer of confinement (i.e., within the drum liner void) at the end of the 60-day shipping period.

The generation of hydrogen within the innermost layer, release across confinement layers and accumulation within the confinement volumes during transport were simulated by numerically solving the system of hydrogen mass balance differential equations for each void volume. The applicable systems of differential equations are listed below. The derivation of these equations follows the system of equations.

SYSTEM OF DIFFERENTIAL EQUATIONS

EQUATION	VOID VOLUME
dX1/dt = C1 - Rlh (X1 - X2) / V1	[drum liner]
dX2/dt = Rlh (X1 - X2)/V2 - Rdf (X2 - X3) / V2	[drum headspace]
dX3/dt = 10Rdf (X2 - X3) / V3	[CNS 10-160B cask IV]

Derivation of the System of Differential Equations

Mass Balance for the Drum Liner Void Volume

$$\frac{dn_1}{dt} = CG - k_{lh}(P_1 - P_2)$$

where,

n1 = Moles of hydrogen inside drum liner void volume (mol)
klh = Effective release rate of hydrogen across the drum liner filter (mol/day-1 atm H2-1)
P1 = Partial pressure hydrogen inside drum liner void volume (atm H2)
P2 = Partial pressure hydrogen inside drum headspace void volume (atm H2).

Applying the ideal gas law and assuming isobaric conditions such that P is constant total system pressure, yields:

$$\frac{PV_1}{RT}\frac{dX_1}{dt} = CG - k_{lh}P(X_1 - X_2).$$

Rearranging terms and defining Rlh as klhRT yields the first equation:

$$\frac{dX_1}{dt} = C_1 - \frac{R_{lh}(X_1 - X_2)}{V_1}.$$

Mass Balance for the Drum Headspace Void Volume

$$\frac{dn_2}{dt} = k_{lh}(P_1 - P_2) - k_{df}(P_2 - P_3)$$

where,

n2	=	Moles of hydrogen inside canister void volume (mol)
kdf	=	Effective release rate of hydrogen across the filter on the drum (mol/day-1 atm H2-1)
P3	=	Partial pressure hydrogen inside CNS 10-160B cask IV void volume (atm H2)

and the other variables are as defined earlier.

Applying the ideal gas law and assuming isobaric conditions such that P is constant total system pressure, yields:

$$\frac{PV_2}{RT}\frac{dX_2}{dt} = k_{lh}P(X_1 - X_2) - k_{df}P(X_2 - X_3).$$

Rearranging terms and defining Rdf as kdfRT yields the second equation:

$$\frac{dX_2}{dt} = \frac{R_{lh}(X_1 - X_2)}{V_2} - \frac{R_{df}(X_2 - X_3)}{V_2}.$$

Mass Balance for the CNS 10-160B Cask Void Volume With Ten Drums

$$\frac{dn_3}{dt} = 10\,k_{df}(P_2 - P_3)$$

where,

n3 = Moles of hydrogen inside CNS 10-160B cask IV void volume (mol).

Applying the ideal gas law and assuming isobaric conditions

$$\frac{PV_3}{RT}\frac{dX_3}{dt} = 10\,k_{df}P(X_2 - X_3).$$

Rearranging terms yields the third equation:

$$\frac{dX_3}{dt} = \frac{10\,R_{df}(X_2 - X_3)}{V_3}.$$

Derivation of the Steady-State Concentrations in Confinement Layers

Prior to transport in the CNS 10-160B cask the concentration of hydrogen within each of the layers of confinement is assumed to be at steady-state. At steady-state the release rates of hydrogen across each layer are equal to the hydrogen gas generation rate. The steady-state concentrations of hydrogen within each volume of confinement were evaluated from the relations below.

At steady-state, the concentration of hydrogen outside the drum is zero (i.e., X3 = 0) and there is no accumulation of hydrogen inside the drum, thus the steady-state hydrogen mass balance for the drum liner void volume becomes:

$$\frac{dX_1}{dt} = 0 = C_1 - \frac{R_{lh}(X_1 - X_2)}{V_1}.$$

For the drum headspace, the steady-state hydrogen mass balance becomes:

$$\frac{dX_2}{dt} = 0 = \frac{R_{lh}(X_1 - X_2)}{V_2} - \frac{R_{df}\,X_2}{V_2}.$$

Rearranging the terms in the mass balance equation for hydrogen at steady-state inside the drum liner,

$$C_1 V_1 = R_{lh}(X_1 - X_2).$$

Substituting this relation in the steady-state equation for the hydrogen mass balance inside the drum headspace and rearranging terms

$$\frac{R_{lh}(X_1 - X_2)}{V_2} = \frac{C_1 V_1}{V_2} = \frac{R_{df}\,X_2}{V_2}.$$

Simplifying the previous equation and solving for the steady-state concentration in the drum headspace, X2, yields

$$X_2 = \frac{C_1 V_1}{R_{df}}.$$

Rearranging the relation for the steady-state hydrogen mass balance inside the drum liner yields:

$$C_1 V_1 + R_{lh}\,X_2 = R_{lh}\,X_1.$$

Rearranging terms in the previous equation and solving for the steady-state hydrogen concentration inside the drum liner, X1, yields

$$X_1 = \frac{C_1 V_1}{R_{lh}} + X_2.$$

The steady-state concentrations were then used to define the initial state of the system (i.e., hydrogen mole fractions within each confinement volume) at the time the CNS 10-160B cask is sealed for transport with a payload of 10 drums.

These systems of differential equations were solved numerically using the Runge-Kutta Fourth Order numerical integration method. Numerical solution implies obtaining the mole fractions of hydrogen in each void volume as a function of time.

For the initial assumed gas generation rate, if the concentration of hydrogen in the innermost void volume is below 0.05 mole fraction, then the hydrogen gas generation rate for the next iteration is increased and the above set of calculations is repeated. If the concentration is greater than 0.05 mole fraction, the gas generation rate for the next iteration is decreased. The evaluation of steady-state hydrogen mole fractions for a given gas generation rate, and simulation of hydrogen generation during transport by numerical integration, continues until two values of the H2 gas generation are evaluated such that for one rate the hydrogen mole fraction in the innermost volume is less than 0.05 and the other results in a mole fraction greater than 0.05. The maximum allowable hydrogen gas generation is estimated to an accuracy of 10-13 mole/sec by refining the gas generation rate interval using the technique of interval halving (Ref. 12.7).

10.4 Determination of Maximum Allowable Decay Limits for Content Codes

The maximum allowable decay heat limit for a content code is determined using RadCalc Software (Ref. 12.8). RadCalc for Windows 2.01 is a windows-compatible software program with applications in the packaging and transportation of radioactive materials. Its primary function is to calculate the generation of hydrogen gas by radiolytic production in the waste matrix of radioactive wastes. It contains a robust algorithm that determines the daughter products of selected radionuclides. The various functions in RadCalc for Windows can be used separately or together. The procedure is outlined below.

The first step in the evaluation of decay heat limits involves determining the activities of the radionuclides and daughters and the associated hydrogen gas generation rate at the time of sealing based on an initial isotopic ratio for the waste. The generation of hydrogen gas by radiolysis is a function of the energy absorbed by the waste. The second step in the evaluation of decay heat limits involves iterating on the total activity (decay heat limit) given the activity fractions from step one until the allowable hydrogen gas generation rate is obtained.

10.4.1 Databases and Input Parameters Used For Calculation of Maximum Allowable Decay Heat Limits

10.4.1.1 Radionuclide Databases

RadCalc uses radionuclide information, calculated gamma absorption fractions for selected container types, and G values to determine decay heat values. Radionuclide information is taken from FENDL/D-1.0 database (Ref. 12.9). The following are a list of radionuclide parameters taken from FENDL/D-1.0 and the values they are used to calculate:

Radionuclide half-lives are used in calculating specific activity

Average heavy particle, beta-type radiation, and gamma radiation energies per disintegration are used in decay heat and hydrogen gas generation calculations

Discrete gamma energies and abundances are used in hydrogen gas generation calculations.

RadCalc uses the ORIGEN2 (Ref. 12.10) database for decay calculations. The decay algorithms calculate the activity of the user specified source and daughter products over a specified period of time and the total number of disintegrations accumulated over this same time interval for each radionuclide. Parameters relevant to these calculations include atomic mass, atomic number, and state. These parameters are used for radionuclide identification and conversions. The decay constant and the branching ratios for decay modes are also used in the decay algorithms.

10.4.1.2 Gamma Absorption Fraction Input Parameters

RadCalc uses the total energy emitted by heavy particle and beta-type decay in calculating the volume of hydrogen produced. However, only a percent of gamma energy will be absorbed in the package and the waste. The absorbed gamma energy is a function of energy, waste density, material type, and geometry. The gamma energy absorbed by the waste is a function of the gamma emission strength, the quantity of gamma ray energy which is absorbed by collision with a waste particle, and the number of particles which interact with the gamma ray. Therefore, gamma energy absorption increases with increasing waste density. For a given waste density, a larger container will contain more particles, and therefore a higher percentage of the gamma ray energy would be absorbed than in a smaller container. The total cumulative absorbed dose for all nuclides and decay modes at time, t is evaluated as:

NR
Dtotal(t) = ACi/ i (0.82Ei + Eiß + Ei + Eix)[1 - exp(- i t)]
i=1

where,

Dtotal(t) = Total cumulative absorbed dose at time, t (rad)

A = A proportionality constant equal to 1.84x1010 rad gram MeV-1 yr-1 Ci-1

Ci = The specific activity of the "i"th nuclide in Curies/gram of waste

i = The decay constant of the "i"th radionuclide (yr-1)

NR = Number of radionuclides

Ei = energy in MeV of the "i"th radionuclide extracted from Flaherty et al. (Ref. 12.11)

Eiß = Average beta energy in MeV of the "i"th nuclide. The average beta energy is approximately one-third of the sum of the possible beta emissions multiplied by the relative abundance of each emission and were obtained from Flaherty et al. (Ref. 12.11).

Eix = The absorbed secondary energy in MeV of the "i"th radionuclide. The secondary radiations result from the transition of a radionuclide from an excited state to the ground state and were obtained from Flaherty et al. (Ref. 12.11).

Ei = The absorbed gamma ray energy in MeV of the "i"th nuclide. The fraction of gamma energy that is absorbed by the waste is a function of the waste density and waste container geometry, and is evaluated for each radionuclide "i" as:

Ei = j nij fij Eij

where,

j = the summation of the fractions of the gamma ray energies absorbed for all gamma emissions of the "i" th nuclide.

nij = the abundance of the "j"th gamma ray per decay of the "i"th nuclide

fij = the fraction of energy, of the "j"th gamma ray of the "i"th nuclide that is absorbed in the waste.

Eij = the energy in MeV, of the "j"th gamma ray of the "i"th nuclide.

RadCalc uses curve fits obtained from Flaherty et al. (Ref. 12.11) and recalculated using the Monte Carlo N-Particle (MCNP) transport code (Ref. 12.12) for ten containers, for obtaining the absorbed gamma dose.

The CNS cask is not currently recognized by the RadCalc. Therefore, another container with dimensions directly proportional to the cask was used for undertaking the calculations.

10.4.1.3 G Value Data

G values for RH-TRU waste are content specific. G values are determined based on the bounding materials present in the payload. The following G values were used for each of the content codes based on the presence of the bounding materials. The G values at 70 F are adjusted to the maximum operating temperature of the CNS cask (168 F) using the Arrhenius equation.

BC 312A
This content code represents solidified organics and does not have a defined G value.

BC 314A
This content code represents cemented inorganic process solids consisting of slugs solidified with cement. It is assumed that water is the dominant hydrogen gas generating material in the waste form and will therefore be the bounding material. The G value for hydrogen from water is 1.6 molecules/100eV. It is also assumed that the moisture content of the waste is 30% and therefore the G value is 30% of the G value for water or 0.48 molecules/100eV (at 70 F).

BC 321A
This content code represents solid organic debris consisting of various combustible and non-combustible items. The dominant material present in this waste is cellulosics (95%) and is therefore considered as the bounding material (TCP-98-01). The G value for hydrogen associated with cellulosics is 3.2 molecules/100eV (at 70 F).

BC 321B
This content code represents organic pool filter and resin waste consisting of ion exchange resins. The dominant material present in this waste is organic resins (80%). The waste also consists of cellulosics (12%). The effective G value for hydrogen for this content code is the sum of 80% of the G value for organic resins (1.7 molecules/100eV at 70 F) and 12% of the G value for cellulosics (3.2 molecules/100eV at 70 F), which is 1.74.

BC 322A
This content code represents waste consisting of glass, metal, and solidified and other inorganic materials. It is conservatively assumed that residual water is the dominant hydrogen gas generating material in this waste form and will therefore be the bounding material. The G value for hydrogen from water is 1.6 molecules/100eV. It is also assumed that the moisture content of the waste is 1% and therefore the G value is 1% of the G value for water, or 0.016 molecules/100eV (at 70 F).

10.4.2 Input Parameters

The input parameters can be placed in three groups: (1) container data, (2) waste data, (3) source data.

10.4.2.1 Container Data

RadCalc requires as input the following parameters associated with the container for which the maximum allowable decay heat limit is being calculated:

Container Type - The payload container for the waste material
Container Dates - Date of generation, date of sealing, and shipping period
Package Void Volume - void volume of the payload container.

A 6- by 6-foot liner with a volume equal to the CNS cask is used to represent the payload container in the RadCalc input file as the RadCalc database does not include the CNS cask. The package void volume for a CNS 10-160B cask is 1938 liters as shown earlier.

10.4.2.2Waste Data

RadCalc requires as input the following parameters associated with the waste for which the maximum allowable decay heat limit is being calculated:

Physical Form - Liquid, Solid, or Gas
Waste volume - volume of the waste, cc
Waste Mass - mass of the waste, g
G value - G value of the waste.

Liquids and gases are prohibited in the CNS 10-160B cask. The volume of waste is assumed to be 217 liters per drum and 2170 liters per canister. The mass of waste is calculated based on the density of the bounding materials for each of the content codes. Based on density data of residential, commercial, and combustible mixed construction debris, the bulk density of the waste materials in content codes BC 321A and BC 321B is 0.36 g/cm3 (Ref. 12.5). A waste true density of 1.5 g/cm3 is assumed for BC 322A, which has steel as the bounding material. Earlier sections provide a discussion on the G value.

10.4.2.3 Source Data

RadCalc requires as input the following parameters associated with the source for which the maximum allowable decay heat limit is being calculated:

Isotopic Composition - List of radionuclides present in the waste
Activity - Reported activities of the listed radionuclides in curies or Becquerel.

10.4.3 Procedure For Determining Maximum Allowable Decay Heat Limits

The necessary inputs are provided to the code prior to initiating a run. A time period of 60 days is conservatively assumed between date of beginning of decay and date of analysis to reflect the shipping period. The model is run with the initial isotopic composition and activity and the corresponding hydrogen gas generation rate is obtained. It is compared with the maximum allowable hydrogen gas generation rate as obtained from Section 10.3, and the scaling factor is obtained by dividing the maximum allowable hydrogen gas generation rate by the RadCalc obtained rate. The isotopic composition is scaled by this differential factor. This is done on the basis of the assumption that the maximum decay heat occurs at the time of maximum activity which will result in the maximum hydrogen gas generation rate. The model is now run so that the hydrogen gas generation rate will now be equal to the maximum allowable hydrogen gas generation rate. The associated decay heat value will be the maximum decay heat limit as the decay heat limit shares a direct relationship with the hydrogen gas generation rate, independent of time.

The results of the decay heat limit modeling are shown in Table 10-1. Methods for demonstrating compliance of the BCL TRU waste with the decay heat and hydrogen gas generation rate limits are shown in Attachment B.

11.0 WEIGHT

11.1 Requirements

The weight limit for a 55-gallon drum is 1,000 pounds. The weight limit for the loaded cask is 14,500 pounds.

11.2 Methods of Compliance and Verification

In accordance with TC-OP-01.4, Segregation and Packaging of TRU Waste, BCLDP shall weigh each payload container and contents on a calibrated scale to determine the total weight of the payload container. Based on the total measured weight of the individual payload containers, BCLDP shall calculate total assembly weight.

12.0 REFERENCES

12.1 U.S. Department of Energy (DOE), 1999, "Waste Acceptance Criteria for the Waste Isolation Pilot Plant," Rev. 7, *DOE/WIPP-069*, U.S. Department of Energy, Carlsbad Area Office, Carlsbad, New Mexico.

12.2 Hatayama, H.K., J.J. Chen, E.R. de Vera, R.D. Stephens, and D.L. Storm, "A Method for Determining the Compatibility of Hazardous Wastes," *EPA-600/2-80-076*, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980.

12.3 Battelle Memorial Institute (BMI), 1993. Memorandum from W.J. Zielenbach to W.J. Madia, Subject: Case RSC-151, JN-1 Criticality System, Battelle Memorial Institute, Columbus, Ohio

12.4 Peterson, S.H., E.E. Smeltzer, and R.D. Shaw, 1990, "Determination of Flow and Hydrogen Diffusion Characteristics of Carbon Composite Filters Used at the Waste Isolation Pilot Plant," Westinghouse STC, Chemical and Process Development, Pittsburgh, Pennsylvania.

12.5 Perry, R.H., D.W. Green, and J.O. Maloney, 1984, *Perry's Chemical Engineers' Handbook*, 6th ed., McGraw-Hill Book Co., New York, New York.

12.6 Connolly, M.J., S.M. Djordjevic, K.J. Liekhus, C.A. Loehr, and L.R. Spangler, 1998, "Position for Determining Gas Phase Volatile Organic Compound Concentration in Transuranic Waste Containers," *INEEL-95/0109*, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho.

12.7 Reklaitis, G.V., A. Ravindran, K.M. Ragsdell, 1983, "*Engineering Optimization: Methods and Application*," John Wiley and Sons, New York, New York.

12.8 McFadden, J.G., "RadCalc for Windows, Version 2.01, Volume II: Technical Manual," Waste Management Federal Services, Inc., Northwest Operations, Richland, Washington.

12.9 FENDL/D Version 1, January 1992 is a decay data library for fusion and (other) applications. Summary documentation by A. B. Pashchenko. Index No. IAEA-NDS-167 in Index to the IAEA-NDS-Documentation Series.

12.10 Croff, A. G., 1980, A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code, *ORNL-5621*, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

12.11 Flaherty, J.E., A. Fujita, C.P. Deltete, and G.J. Quinn, 1956, "A Calculational Technique to Predict Combustible Gas Generation in Sealed Radioactive Waste Containers," *GEND 041*, EG&G Idaho, Inc., Idaho Falls, Idaho.

12.12 Breismeister, J.F., editor, "MCNP—A General Monte Carlo N-Particle Transport Code," Version 4a, Los Alamos National Laboratory Report LA-12625, Los Alamos, New Mexico.

ATTACHMENT A

REMOTE-HANDLED TRANSURANIC CONTENT CODES AND CHEMICAL LISTS FOR BATTELLE COLUMBUS LABORATORIES

CONTENT CODE: BC 312A

CONTENT DESCRIPTION: Solidified Organic Waste

WASTE DESCRIPTION: This waste consists of solidified organic and inorganic liquid wastes.

GENERATING SOURCES: This waste is generated during research and development activities conducted in Building JN-1.

WASTE FORM: The waste consists primarily of inorganic and organic liquids that have been solidified using Floor Dry. The inorganic liquids included acids and acid solutions, and elemental mercury. The organic liquids included hydraulic oil, waste water, sludge of sand and mixed fission products (dust, small fragments); small items such as tools may also be present; nonhalogenated organic liquids such as glycols, oils, and alcohols, and unmarked bottles of liquids.

WASTE PACKAGING: The waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum is lined with a steel liner. Ten drums will then be placed into the CNS 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic information required to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. A combination of assay of samples and modeling the isotopic generation processes results in the establishment of a mixture that characterizes the waste in the content code and the majority of waste at the BCLDP. Using shipping package modeling, dose rate and weight measurements based on the mixture then allows the BCLDP to determine the isotopic inventory. As required, additional radioassay (e.g., confirming gamma spectrometry) will be performed.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Absorbents such as Radsorb or diatomaceous earth (e.g., Floor Dry) will be added to any waste matrix that has the potential to dewater after packaging.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. The steel liner is fitted with a filter with a hydrogen diffusivity of 3.7E-06 mole/second/mole fraction.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 3.5082E-08 moles per second per drum and 3.5082E-07 moles per second per CNS 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: There is no decay heat limit for this content code as no G values have been established. Waste cannot be transported under Option 2.

BATTELLE COLUMBUS LABORATORIES CONTENT CODE BC 312A
SOLIDIFIED ORGANIC WASTE

MATERIALS AND CHEMICALS >1%

DIATOMACEOUS EARTH (FLOOR DRY)
ACIDS AND ACID SOLUTIONS
MERCURY
HYDRAULIC OIL, GLYCOLS, OILS, AND ALCOHOLS
SAND

MATERIALS AND CHEMICALS <1%

METALS (including stainless steel, aluminum, iron, copper, lead, beryllium, and zirconium)

CONTENT CODE: BC 314A

CONTENT DESCRIPTION: Cemented Inorganic Process Solids

WASTE DESCRIPTION: This waste consists of slugs produced from dissolving fuel specimens in an acid solution that was then diluted several times and mixed with cement and water and allowed to solidify in foam cups.

GENERATING SOURCES: This waste is generated during repackaging of the waste materials generated from research and development activities conducted in Building JN-1.

WASTE FORM: The waste consists of slugs produced from dissolving fuel specimens in an acid solution which was then diluted several times and mixed with cement and waster and allowed to solidify in foam cups. The slugs will contain limited amounts of radionuclides from fuel because of this dilution. The waste matrix will also include Floor Dry added during repackaging to absorb any water from condensation or dewatering.

WASTE PACKAGING: The waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum is lined with a steel liner. Ten drums will then be placed into the CNS 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic information required to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. A combination of assay of samples and modeling of the isotopic generation process used in the establishment of a mixture that characterizes the waste in the content code and the majority of waste at the BCLDP. Using shipping package modeling, dose rate and weight measurements based on the mixture then allows the BCLDP to determine the isotopic inventory. As required, additional radioassay (e.g., confirming gamma spectroscopy) will be performed.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Absorbents such as Radsorb or diatomaceous earth will be added to any waste matrix that has the potential to dewater after packaging.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. The steel liner is fitted with a filter with a hydrogen diffusivity of 3.7E-06 mole/second/mole fraction.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 3.5082E-08 moles per second per drum and 3.5082E-07 moles per second per CNS 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit is 0.738 watts per drum and 7.38 watts per CNS 10-160B cask.

**BATTELLE COLUMBUS LABORATORIES CONTENT CODE BC 314A
CEMENTED INORGANIC PROCESS SOLIDS**

MATERIALS AND CHEMICALS >1%

DIATOMACEOUS EARTH (FLOOR DRY)
SLUGS

MATERIALS AND CHEMICALS <1%

NITRIC ACID
WATER

CONTENT CODE: BC 321A

CONTENT DESCRIPTION: Solid Organic Waste

WASTE DESCRIPTION: This waste consists of a variety of combustible and noncombustible items.

GENERATING SOURCES: This waste is generated from activities supporting the decontamination and decommissioning of Building JN-1 under the Battelle Columbus Laboratories Decommissioning Project (BCLDP).

WASTE FORM: The waste may include combustible items such as cloth and paper products (e.g., from the cleanup of spills), rags, coveralls and booties, plastic, cardboard, rubber, wood, surgeons gloves, and Kimwipes. The waste may also include filter waste (e.g., pool filters, dry box filters, HEPA filters, and filter cartridges); noncombustible Benelex and Plexiglas neutron shielding, blacktop, concrete, dirt, and sand; leaded gloves and aprons comprised of Hypalon rubber and lead oxide impregnated neoprene; and small amounts of metal waste. The waste may also include particulate and sludge-type organic process solids immobilized/solidified with Portland cement, vermiculite, Aqua-Set, or Petro-Set.

WASTE PACKAGING: The waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum is lined with a steel liner. Ten drums will then be placed into the CNS 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic information required to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. A combination of assay of samples and modeling of the isotopic generation process, results in the establishment of a mixture that characterizes the waste in the content code and the majority of waste at the BCLDP. Using shipping package modeling, dose rate and weight measurement based on the mixture then allows the BCLDP to determine the isotopic inventory. As required, additional radioassay (e.g., confirming gamma spectroscopy) will be performed.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Absorbents such as Radsorb or diatomaceous earth will be added to any waste matrix that has the potential to dewater after packaging.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. The steel liner is fitted with a filter with a hydrogen diffusivity of 3.7E-06 mole/second/mole fraction.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 4.093E-08 moles per second per drum and 4.093E-07 moles per second per CNS 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit is 0.158 watts per drum and 1.58 watts per CNS 10-160B cask.

BATTELLE COLUMBUS LABORATORIES CONTENT CODE BC 321A
SOLID ORGANIC WASTE

MATERIALS AND CHEMICALS >1%

CELLULOSICS
RUBBER
DIATOMACEOUS EARTH (FLOOR DRY)
GLASS
ION EXCHANGE RESIN
IRON-BASED METAL/ALLOYS
PAPER
PLASTIC
RADSORB
CLOTH
CARDBOARD
WOOD
KIMWIPES
FILTERS
BENELEX
PLEXIGLAS
CONCRETE AND NEOPRENE
PORTLAND CEMENT
VERMICULITE
AQUA-SET/PETRO-SET
OTHER INORGANICS

MATERIALS AND CHEMICALS <1%

METALS (including aluminum, lead, zirconium, stainless steel, and carbon steel)

CONTENT CODE: BC 321B

CONTENT DESCRIPTION: Solid Organic Waste

WASTE DESCRIPTION: This waste consists of a variety of combustible and noncombustible items.

GENERATING SOURCES: This waste is generated during the change-out of resins in the Transfer/Storage Pool filtering system in Building JN-1 (Hot Cell Laboratory).

WASTE FORM: The waste may include filter waste (e.g., pool filters); nuclear grade resin, resin bags, paper, rubber gloves, Floor Dry bags, seals, hoses, valves, and clamps.

WASTE PACKAGING: The waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum is lined with a steel liner. Ten drums will then be placed into the CNS 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic information required to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. A combination of assay of samples and modeling the isotopic generation process results in the establishment of a mixture that characterizes the waste in the content code. Using shipping package modeling, dose rate and weight measurements based on the mixture then allows the BCLDP to determine the isotopic inventory. As required, additional radioassay (e.g., confirming gamma spectrometry) will be performed.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Absorbents such as Radsorb or diatomaceous earth will be added to any waste matrix that has the potential to dewater after packaging.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. The steel liner is fitted with a filter with a hydrogen diffusivity of 3.7E-06 mole/second/mole fraction.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 4.093E-8 moles per second per drum and 4.093E-7 moles per second per CNS 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit is 0.269 watts per drum and 2.69 watts per CNS 10-160B cask.

BATTELLE COLUMBUS LABORATORIES CONTENT CODE BC 321B
SOLID ORGANIC WASTE

MATERIALS AND CHEMICALS >1%

CELLULOSICS (12 weight %)
RUBBER
DIATOMACEOUS EARTH (FLOOR DRY)
ION EXCHANGE RESIN (80 weight %)
IRON-BASED METAL/ALLOYS
PAPER
PLASTIC
RADSORB
RESIN BAGS
FILTERS
OTHER INORGANICS

MATERIALS AND CHEMICALS <1%

METALS (including aluminum, lead, zirconium, stainless steel, and carbon steel)

CONTENT CODE: BC 322A

CONTENT DESCRIPTION: Solid Inorganic Waste

WASTE DESCRIPTION: This waste consists of a variety of glass and metal materials.

GENERATING SOURCES: This waste is generated during repackaging of the waste materials generated from research and development activities conducted in Building JN-1.

WASTE FORM: The waste consists primarily of glass and metal debris. Glass debris includes laboratory glassware, windows, leaded glass windows, and various glass apparatus. Metal items may include deteriorated berry cans, cable, wire, planchets, signs, valves, piping, strapping, tools, foils, sheeting, fixtures, equipment (e.g., pumps or motors that have had all oil or any other free liquids removed up to an allowance of 1%), hardware (e.g., nuts, bolts, brackets), specimen vials, fuel rod cladding, metallurgical mounts, and lead lined tubing. Metals of construction include stainless steel, aluminum, iron, copper, lead, beryllium, and zirconium.

WASTE PACKAGING: The waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum is lined with a steel liner. Ten drums will then be placed into the CNS 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic information required to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. A combination of assay of samples and modeling of the isotopic generation process used in the establishment of a mixture that characterizes the waste in the content code and the majority of waste at the BCLDP. Using shipping package modeling, dose rate and weight measurements based on the mixture then allows the BCLDP to determine the isotopic inventory. As required, additional radioassay (e.g., confirming gamma spectroscopy) will be performed.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Absorbents such as Radsorb or diatomaceous earth (e.g., Floor Dry) will be added to any waste matrix that has the potential to dewater after packaging.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. The steel liner is fitted with a filter with a hydrogen diffusivity of 3.7E-06 mole/second/mole fraction.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 3.5082E-8 moles per second per drum and 3.5082E-7 moles per second per CNS 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit is 22.1 watts per drum and 221 watts per CNS 10-160B cask.

BATTELLE COLUMBUS LABORATORIES CONTENT CODE BC 322A
SOLID INORGANIC WASTE

MATERIALS AND CHEMICALS >1%

CEMENT
DIATOMACEOUS EARTH (FLOOR DRY)
GLASS
METALS (including stainless steel, aluminum, iron, copper, lead, beryllium, and zirconium)
IRON-BASED METAL/ALLOYS
OTHER INORGANICS
SLUGS

MATERIALS AND CHEMICALS <1%

CARBON TETRACHLORIDE
1,1,1-TRICHLOROETHANE
TRICHLOROETHYLENE
ACETONE
METHANOL
BENZENE
METHYL ETHYL KETONE
NITRIC ACID
WATER

ATTACHMENT B

METHODOLOGY FOR DETERMINATION OF DECAY HEATS AND HYDROGEN GAS GENERATION RATES FOR REMOTE-HANDLED TRANSURANIC (RH-TRU) CONTENT CODES FOR BATTELLE COLUMBUS LABORATORIES

1.0 INTRODUCTION

All Battelle Columbus Laboratories Decommissioning Project (BCLDP) remote-handled transuranic (RH-TRU) waste to be transported in the CNS 10-160B cask shall comply with the 5% (by volume) limit on hydrogen concentration during transport. If a bounding G value and decay heat limit have been established for the approved content code, compliance with the decay heat limit shall be evaluated pursuant to this attachment for the individual containers under the content code. If compliance with the decay heat limit cannot be demonstrated, the hydrogen generation rate of the container shall be determined as outlined in this attachment and compared to the hydrogen gas generation rate limit specified for that approved content code. If the container meets the limit, it is eligible for shipment if all other transportation requirements are met. If the container does not meet the limit, it cannot be shipped and shall be segregated for repackaging or other mitigation measures.

2.0 DECAY HEAT METHODOLOGY

This section describes the general features of nondestructive assay and destructive assay methods used in conjunction with acceptable knowledge by the BCLDP.

The isotopic content for an identified waste stream is determined by a combination of (1) representative waste stream sample analyses and (2) conservative application of ORIGEN code values for isotopes expected to be present in spent nuclear fuel, but not represented by the sample analyses. The determinations are verified on an approved, periodic basis by sample submission to the BCLDP Radioanalytical Laboratory (RAL) for gamma and/or alpha spectroscopy. In certain circumstances, field gamma isotopic screening may be implemented to differentiate between photon-emitting isotopes, which facilitates Cs-137 correlation to TRU waste components.

The RAL operates under a QA plan that is consistent with the requirements of U.S. Department of Energy Order 5700.6C and the American National Standards Institute/American Society of Mechanical Engineers NQA-1. In addition, an internal RAL quality control program ensures that the analytical results are reliable and that data integrity is maintained throughout the measurement system. If gamma and/or alpha spectroscopy results for periodic samples indicate the presence of source terms other than those initially determined for an identified waste stream, the model is amended to incorporate the appropriate source terms.

It is expected that there will be three specific source terms for the West Jefferson North (JN) facility, which is the primary focus of the BCLDP decontamination and decommissioning activities:

- JN Standard Isotopic Mix (applicable to general contamination at Building JN-1)
- JN Hot Cell Specific Isotopic Mix

- JN-1 Pool Cleanup Isotopic Mix.

During waste packaging, BCLDP personnel will inventory the waste items loaded into each payload container and document the source location (hot cell, pool, etc.) for each waste item. This inventory is used to select the proper isotopic mix for the waste items. Only waste items from the same source location will be packaged together to ensure the correct assignment of isotopic mix to each loaded payload container. If an isotopic mix for a specific source location is not established, the methodology will be amended to incorporate the appropriate source terms, spreadsheets, and any other tools needed to facilitate assessment of the quantities and nature of the isotopes involved.

After the isotopic mix is established, the expected external dose rates for 1 millicurie of the mix are estimated for different packaging configurations using an appropriate conservative matrix. From the measured weights and dose rates of the payload containers, the quantity of radionuclides in each container can be determined. A computer program is used by the BCLDP to determine compliance with the limits on the following transportation and disposal parameters for RH-TRU waste based on the inputs of payload container dose rate, weight, and source:

- Fissile grams equivalent
- Decay heat.

The application of the ORIGEN code in the proposed BCLDP TRU WCP methodology for determining radioassay properties for RH-TRU wastes is conservative. In addition, associated measurement errors and assumptions have been conservatively estimated to determine a total error that is bounding for the methodology.

3.0 OBJECTIVES OF THE GAS GENERATION TESTING

The maximum allowable hydrogen gas generation rates for the RH-TRU content codes for the BCLDP are provided in Table 10-1 of this appendix. Compliance with the hydrogen gas generation rate shall be demonstrated by testing. Compliance with the requirements of this test plan should be documented in site-specific procedures under a documented quality assurance program.

4.0 GAS GENERATION TEST METHODOLOGY

The following sections describe how compliance with the limit on the hydrogen gas generation rate will be implemented for each authorized content code for BCLDP.

Demonstration of Compliance With Hydrogen Gas Generation Limit

During the course of the testing, the headspace gas of the selected waste containers will be sampled and analyzed to determine the concentrations of hydrogen and other gases that are produced by radiolysis or present when the waste was packaged. Sampling lines that communicate with the headspace of the waste containers will be installed. Samples of the headspace gas will be withdrawn periodically and analyzed using a gas chromatograph and/or a mass spectrometer. The analytical results will be used to calculate the hydrogen gas generation rate. The measured hydrogen gas generation rate will be compared to the appropriate hydrogen gas generation limits for each content code to evaluate compliance with transportation requirements.

Because all layers of confinement in all the containers have been vented since the time of generation and the containers have been in a vented condition for a period of time, steady-state hydrogen concentrations exist within all void volumes inside a container. At steady-state conditions, the rate of gas generation by radiolysis equals the release rate of gas across each layer of confinement. The measured hydrogen gas concentration in the headspace gas will be used to calculate the hydrogen gas generation rate.

The hydrogen gas generation rate of the waste container is calculated from the measured hydrogen gas concentration using the following relationship:

$$C_g = X_H \; x \; L_{CF}$$

where,

C_g = the hydrogen gas generation rate (mole/sec)
X_H = the measured concentration of hydrogen gas in the waste container headspace (mole fraction)
L_{CF} = diffusion characteristic of the waste container filter.

The rate shall be compared to the appropriate limit for the content code. The container shall be qualified for shipment only if the limit is met.

Another method may also be used when the final waste form is a solid monolith of evaporated/solidified inorganic wastes (BC 312A or 314A) that will be directly placed into drums. Process controls will be used to ensure homogeneity of the sludge. A small sample of the waste will be analyzed for its gas generation properties. The hydrogen gas generation rate for the drum can then be determined based on the mass of waste in the drum. For example, a sludge sample can be placed in a sealed test chamber of known volume. The concentration of hydrogen will be measured in the chamber after an elapsed period of time, and the following relationship will be used to calculate the hydrogen gas generation rate from the sample:

$$C_{g,\,sample} = \frac{X\,P\,V_{chamber}}{R\,T\,\Delta t}$$

where,

$C_{g,sample}$ =	hydrogen gas generation rate from sample (mol/sec)	
X	=	mole fraction hydrogen in the test chamber
P	=	absolute ambient pressure (atm)
$V_{chamber}$ =	volume of the test chamber (L)	
R	=	gas law constant (0.08206 atm L mol^{-1} K^{-1})
T	=	absolute ambient temperature (K)
t	=	elapsed time (sec).

$$C_{g,\,drum} = C_{g,\,sample}\,\frac{m_{drum}}{m_{sample}}$$

The hydrogen gas generation rate will be calculated on a drum basis using the following relationship:
where,

$C_{g,drum}$	=	hydrogen gas generation rate in drum (mol/sec)
m_{drum}	=	mass of waste form in drum (g)
m_{sample}	=	mass of sample (g).

The actual drum hydrogen gas generation rate will be compared to the maximum allowable hydrogen generation rate limit in Table 10-1 of this appendix.

Attachment 3
Suggested Language for the Certificate of Compliance

Suggested Language for the Certificate of Compliance

Add to Condition 11

11 (c) For any package containing TRU waste generated by DOE or its contractors, the following additional conditions apply:
(1) Waste content codes and classification, physical form, chemical properties, chemical compatibility, gas distribution and pressure buildup, container and contents configuration, isotopic characterization and fissile content, decay heat and hydrogen generation rate limits, and weight must be determined and limited in accordance with Appendix 4.10.2 of the application;
(2) Each waste container must not exceed the hydrogen gas generation rate or the decay heat limits specified in Appendix 4.10.2 of the application; and
(3) One or more filter vents must be installed in the outermost waste container. Filter vents must meet the minimum specifications of Appendix 4.10.2 of the application.